

Using the Social-Ecological Systems Framework to Evaluate Green Infrastructure: Coastal management case studies from Vietnam and Bangladesh

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Abstract

In early 2015, The Nature Conservancy will complete an initial global assessment of disaster risk reduction, including green infrastructure strategies. The organization is particularly interested in studying the additional benefits of flood and storm risk reduction projects. This paper examines green infrastructure approaches for disaster risk reduction, using mangrove restoration and mangrove management projects from Bangladesh and Vietnam. Even though mangroves are seen as a valuable resource for green infrastructure by NGOs and international development agencies, long-standing mangrove forests are being degraded and destroyed, often by shrimp aquaculture. Mangrove rehabilitation and planting efforts are of little use if the stands are not protected afterward. Elinor Ostrom

This report has shown there can be many factors that can result in a gap between intent and the outcomes. The paper has six recommendations for The Nature Conservancy, other NGOs, and international agencies looking to develop mangrove restoration projects. First, the risk framework used to evaluate disaster risk reduction should be modified to incorporate social vulnerability and resiliency. Next, further study should be done to quantify the disaster risk reduction potential of mangroves. Third, any mangrove project implemented for disaster risk reduction should consider implementing a dike system in addition to the mangroves. Fourth, the Social-Ecological System diagnostic framework developed by Elinor Ostrom could be used as a tool for evaluating the implementation of disaster risk reduction and green infrastructure projects. The fifth recommendation is to use the eight principles for governing the commons to inform best practices for project design. Finally, learning from case studies, such as the ones in this report, can yield improved approaches implementing green infrastructure for disaster risk reduction.

1. Introduction

Climate change is increasing the intensity of storm and flood events, particularly affecting coastal areas. The Nature Conservancy, an international NGO, is looking at how green infrastructure approaches can address disaster risk reduction while also playing an important role in meeting other development goals. This has implications for other international agencies and NGOs doing similar work. This is especially important as green infrastructure projects, such as mangrove ecosystems, use the same land that is typically used for agriculture or aquaculture purposes, thus raising the need for better understanding of competing actors, users, and desired outcomes.

The objectives of this paper are fourfold. The first objective is to clarify the definition of green infrastructure. Next, the disaster risk framework that is typically used by international agencies and NGOs, including The Nature Conservancy is discussed in the context of literature on climate adaptation and disaster reduction. The third objective is to evaluate mangroves as both a tool of green infrastructure and as a technique for disaster risk reduction. The final objective is to evaluate these two case studies using the social-ecological framework developed over many years by Dr. Elinor Ostrom and others to address issues around self-governance of common pool resources (Cinner, et al. 2013). These projects are analyzed because of their goal of reducing disaster risk and improving resiliency through implementation of mangrove afforestation and restoration projects. One project comes from Vietnam and is funded by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) [formerly the GTZ]. The other comes from Bangladesh, funded by multiple partners including the United Nations Development Programme (UNDP), the Government of Bangladesh, and the Global Environmental Facility

(GEF). The case comparison is used to provide policy recommendations to NGOs and international development agencies that are working to implement successful mangrove projects.

2. Background on Green Infrastructure, Disaster Risk Reduction, and Mangroves

2.1 Green Infrastructure

Green infrastructure can be defined in a variety of ways. McMahon and Benedict (2006) define it as “an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations,” with the purpose of sustaining natural life and maintaining environmental, social, and economic sustainability (p.5). Green infrastructure is used to benefit human populations while also contributing to biodiversity conservation through the creation or improvement of a network of natural areas (Naumann, et al. 2010). It emphasizes the creation of corridors of green space, designing interconnections between habitats (Gill, et al. 2007; Tzoulas, et al. 2007; Davies, et al. 2008). Green infrastructure is implemented to increase resilience and sustainability by protecting business operations (Dow Chemical Company, et al. 2013) and support improved human health (Tzoulas, et al. 2007).

Green infrastructure is often portrayed as something specific to an urban or peri-urban setting (Gill, et al. 2007; Tzoulas, et al. 2007; Dunn 2010; U.S. EPA Water 2014), though it can be rural as well (Davies, et al. 2008; Naumann, et al. 2010). In an urban setting, “rain gardens, vegetated swales, pocket wetlands, constructed wetlands, open space, urban agriculture and farming, and vegetated median strips— essentially soil and vegetation incorporated into the urban landscape— and engineering techniques which foster such incorporation such as green roofs, tree boxes, infiltration planters, and permeable pavement” (Dunn 2010) are examples of green infrastructure. Green infrastructure can be seen as “the physical environment within and between our cities, towns and villages. It is a network of multi-functional open spaces, including

formal parks, gardens, woodlands, green corridors, waterways, street trees and open countryside” (Davies, et al. 2008). The main characteristics of green infrastructure include (Naumann, et al. 2010, p. 15):

- Critical mass: not one tree but many trees
- Benefits to people: services provided to humans
- Multi-functionality: not only nature conservation or public recreation; multiple objectives
- Substitutability with hard infrastructure: instead of something constructed, using something natural, though it may still need investment and maintenance

Green infrastructure projects can be used to protect against the three categories of flood events: pluvial (rainfall), fluvial (river), and coastal. For example, Table 2.1.1 shows how green infrastructure can be used to replace traditional engineered (hard) methods. This is a reason why green infrastructure is sometimes called “soft environmental engineering” (Tompkins, et al. 2013, p. 15). Major rainfall events are problematic for cities: as the proportion of impervious surface area increases, the infiltration potential decreases (Zevenbergen, et al. 2010). Increasing the area available to capture rainfall, instead of diverting it through drainage channels, allows for improved infiltration. The main nature-based techniques used to help limit the impact from this category of events include bioswales, retention parks, and green roofs. Bioswales are vegetated channels that provide natural treatment and retention as stormwater runs through (U.S. EPA Water 2014). Retention parks hold stormwater for extended periods, compared to drainage channels, giving water more chance to infiltrate (Marchand, et al. 2012, p. 16, 21). Green roofs are covered with vegetation and growing media that enable rainfall infiltration and future evapotranspiration of water (U.S. EPA Water 2014). Flood plains in their natural state absorb floodwaters and allow rivers to fluctuate (Renaud, et al. 2013, p. 10). Wetlands do the same, along both rivers and coastal regions (Renaud, et al. 2013, p. 10), Mangrove forests can help reduce the impact of increased wave action from storm surges and tsunamis (Marchand, et al.

2012, p. 15). Reefs also provide a natural method for reducing wave energy (Marchand, et al. 2012, p. 12). While this list is not exhaustive, it provides a brief overview of various green infrastructure measures that are used to minimize impacts from the three categories of flood events.

Table 2.1.1. Traditional measures and green infrastructure and nature-based alternatives against pluvial, fluvial and coastal flood events.

Flood Event	Process Description	Traditional Measures	Green Infrastructure Measures
Pluvial	Large quantities of precipitation and decreased infiltration possibilities due to increased impervious surface	Drainage channels	Bioswales Retention parks Green roofs Urban forestation
Fluvial	Large river discharges leading to expansion of the river in the entire floodplain or overtopping/failure of the embankments enhanced by increased infilling of wetlands and encroachment in the river floodplains	Embankments Dams	Floodplain widening/zoning Wetland restoration Upstream wetland and forest restoration
Coastal	Storm surges, tsunamis, or swell waves result in increased water levels and high waves	Seawalls Breakwaters	Restoration and conservation of mangroves/marshes/dune and beach systems Restoration and conservation of coral and shellfish reefs

Source: Adapted from Li, et al. 2012, Figure 2.2.

These green infrastructure (GI) techniques have been used across the world and by various types of organizations, including local governments, federal governments, international organizations like the World Bank, non-profits, and non-governmental organizations (NGOs). For example, the implementation of green roofs in Malmo, Sweden began as an initiative of the city government and local housing authority (Kazmierczak and Carter 2010, p. 89-95). There are NGOs that also support the implementation of green roofs, assisting locals with using this method. In the Netherlands, the Room for the River initiative is managed by seventeen government agencies, ranging from the federal level to municipalities (Marchand, et al. 2012, p. 33). Shell Pipeline Company and The Nature Conservancy have started oyster reef projects in

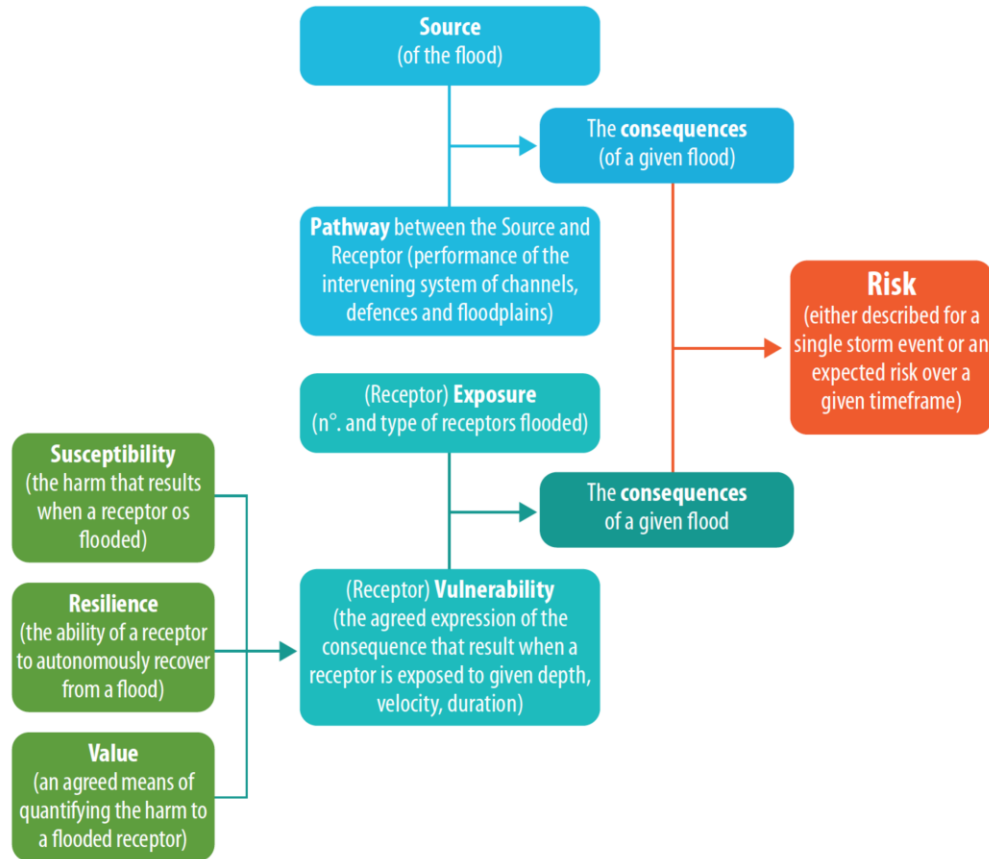
Louisiana to better protect the coastline (Dow Chemical Company, et al. 2013, p. 18-20). The World Bank has funded coral reef restoration projects in locations such as Indonesia, the Maldives, and along southwestern Africa. The mangrove projects compared in this paper were funded by national governments, the United Nations, and other international agencies.

2.2 Definition of Disaster Risk Reduction and Its Components

Often, green infrastructure projects for flood control are implemented with one overall goal in mind: improving the flow of water to reduce the risk of disaster. But what is disaster risk reduction? According to the United Nations Office for Disaster Risk Reduction (UNISDR), “Disaster Risk Reduction (DRR) aims to reduce the damage caused by natural hazards like earthquakes, floods, droughts and cyclones, through an ethic of prevention” (UNISDR 2012). DRR looks to minimize the impact of future disasters by acting proactively instead of after a disaster occurs. As climate change becomes a greater problem around the world, DRR is being used as an adaptation strategy. Yet the traditional Damage and Loss Assessment (DaLA) Methodology used by the World Bank and UN among others to evaluate the effectiveness of DRR projects does not include non-market value costs, such as the disruption of social cohesion that make recovery even more difficult and expensive (Kellett and Caravani 2013, p. 9). This is also seen in the typical components used to evaluate natural disaster risk reduction: most components are economic in nature, including savings from protection of the built environment, protection of tourism sector and businesses, and economic opportunities the project provides (Sayers, et al. 2013, p. 72). The dimensions of risk according to major international organizations, shown in Figure 2.2.1, include components of the built environment – receptors, infrastructure that is subject to damage (Sayers, et al. 2013, p. 24). These dimensions of risk include source, pathway, exposure and vulnerability. Vulnerability to risk itself is built on

dimensions of susceptibility (harm that results), resilience (ability to automatically recover), and value (quantification of harm).

Figure 2.2.1. The components of risk.



Source: Figure from Sayer, et al. 2013, Figure 2.

2.2.1 Social Vulnerability and Resiliency

While The Global Facility for Disaster Reduction and Recovery (GFDRR) within the World Bank uses the DaLA Methodology, which focuses on the overall economy of the affected country, the organization recognizes that there is important research being done on the non-market, social costs of disasters (Kellett and Caravani 2013, p. 9). Evaluation based on economics typically only addresses the built environment, leaving out social relationships (Costanza and Farley 2007, p. 251). In 2012, the number of people displaced by disasters reached more than 32 million (Kellett and Caravani 2013, p. 2). It is important to recognize

human networks and social vulnerability in understanding the impact of disasters (Costanza and Farley 2007, p. 250) and the disaster risk reductions that DRR projects can affect. To incorporate this and other human elements, Sultana, et al. (2013) looked at factors of hazard, exposure, and vulnerability in terms of the physical, social, economic, and environmental systems to calculate risk.

This shows that, just like the built environment and the economy, vulnerability can also be measured for social outcomes and human security. Individuals and groups of people are not affected identically (O'Brien, et al. 2007, p. 77), nor is every individual within a community affected in the same way (Adger 1999, p. 251). There is differential susceptibility of groups and individuals to losses from natural disasters because of diversity in income and social status within a community (Adger 1999, p. 252). Those who are the poorest and most marginalized, living in larger households in the highest-risk areas are those who feel the greatest impact from natural disasters (World Bank 2013, p. vii; Sultana, et al. 2013, p. 45).

“Social vulnerability is a multidimensional concept that helps to identify those characteristics and experiences of communities (and individuals) that enable them to respond to and recover from environmental hazards” (Cutter, et al. 2003, p. 257). This means that resilience is also a factor in human vulnerability, just as it is for receptor vulnerability to disasters. Socio-economic factors can determine the differential potential of communities to adapt to changing conditions (Füssel and Klein 2006, p. 317); those with poorer populations, as mentioned previously, would have more difficulty adjusting to natural disasters. By focusing on social vulnerability, institutions can see who would be most affected by natural disasters (Füssel and Klein 2006, p. 305, 317). This could lead to the creation of social protection systems that provide a buffer for individuals from shocks (World Bank 2013, p. 33). Therefore, forming institutional

methods to deal with potential disasters is important and could be considered a component of DRR.

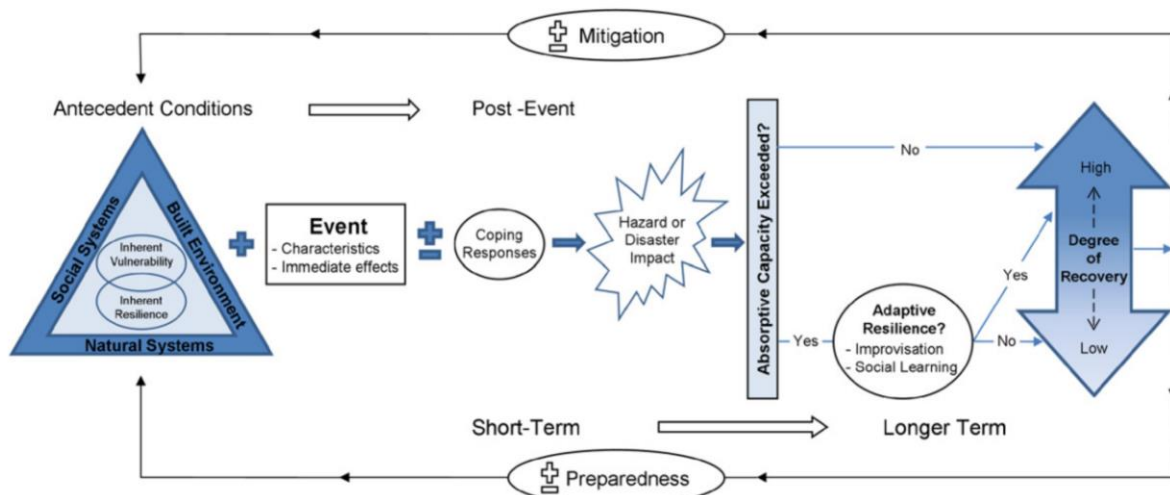
In addition, social perception of risk and risk events can cause differences in the overall outcome (Slovic and Weber 2002). If an individual does not believe that there is risk to his or her person, they might not leave in the face of a storm, as evidenced in Hurricane Katrina. In this same example, there were people who were unable to leave because they did not have the money to do so. Social factors and perceptions both influence the risk of an individual and a community to a disaster. Furthermore, disaster risks induced by climate change have the potential to lead to intercommunal conflict, though there is not much evidence of this happening yet (Gleditsch 2012, p. 5). The interpretation of vulnerability and risk affects the type of adaptation that is promoted (O'Brien, et al. 2007, p. 83-84). This means that framing disaster risks of climate change in a human security context could have an impact on the type of risk reduction strategy that would be used.

Therefore, the risk framework shown in Figure 2.2.1 is not enough as its focus is only on the built environment. A full understanding of risk reduction needs to include a social vulnerability component. Social vulnerability can be determined by factors of personal wealth, age, density, economic dependence on a single-sector, housing (nature of material and ownership), race, ethnicity, occupation, and infrastructure dependence (Cutter et al. 2003, p. 251-254; context of the U.S.). An example of this comes from *Social Vulnerability to Climate Change in California*, which looks at nineteen factors across census tracts (Cooley, et al. 2012, p. 19-21). Knowing the social vulnerability of the population in a project area is vital, so adapting this index to fit in a province/village context for other countries is important. While risk and resiliency are connected, thinking about the outcome as resilience of the system incorporates

more social factors than considering risk alone. As such, Figure 2.2.1.1 shows risk in the context of social vulnerability and resilience, as the most important outcome of risk reduction is protecting human lives and livelihoods for recovery after a disaster.

The figure also includes the inherent resilience. Resilience is often identified as “the ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions” (World Bank 2013, p. 4). In a social vulnerability context, resilience is the capacity of society to draw on reservoirs of practices, knowledge, values, and worldviews to better prepare the system for change (Adger, et al. 2005, p. 1037). Therefore, incorporating local knowledge and knowledge from across systems is necessary. This can be done through adaptive governance, explained in more detail in section 4.1.

Figure 2.2.1.1. Schematic representation of the disaster resilience of place (DROP) model.



Source: Adapted from Cutter, et al. 2008, p. 602, Figure 2.

2.2.2 Green Infrastructure as Disaster Risk Reduction

Japan and the World Bank are the primary financiers of disaster risk reduction projects, with many projects concentrated in middle-income countries (Kellett and Caravani 2013). The

poorest countries receive less than 20 percent of DRR financing (Kellett and Caravani 2013, p. ii). Most DRR projects for flooding focus on large infrastructure (Kellett and Caravani 2013, p. 11), such as dams and levees. The favored intervention approach for flooding continues to be these hard engineered structures (Renaud, et al. 2013, p. 6). Hard engineered structures are designed to withstand a certain flood level, whereas green infrastructure is used to mitigate flood effects, not necessarily to completely prevent flooding. Green infrastructure can provide additional benefits, including mitigation, adaptations, and development, while a structure like a levy is there for the sole purpose of mitigating flooding (Tompkins, et al. 2013, p. 15; Jones, et al. 2012, p. 506). In addition, the use of green infrastructure can be much more cost effective than the use of hard engineered structures. For example, the annual cost of maintaining mangrove forests is estimated at \$7.50 per hectare versus \$287.50 for maintaining a hectare of sea dikes (Jones, et al. 2012, p. 507).

DRR calls for resiliency of the built and natural systems, whereas hard structures only focus on built systems. DRR has similarities to green infrastructure, as green infrastructure is defined as being sustainable and resilient (Dow Chemical Company, et al. 2013, p. 3). The International Strategy for Disaster Reduction, which promotes DRR, prioritizes environmental and natural resource management (Renaud, et al. 2013, p. 7). Green infrastructure projects, as they are characterized by providing multiple benefits, can offer developmental and environmental benefits, in addition to storm protection benefits (see Figure 2.2.2.1). The connection of green infrastructure to exposure, hazard, and vulnerability, elements of risk (as seen in Figure 2.2.2.2), are shown in Figure 2.2.3. This shows how green infrastructure techniques can be used to reduce risk by targeting multiple aspects of risk.

The central goal and outcome of DRR is the protection of lives and livelihoods. If coastal areas are at risk due to climate change, is it appropriate to develop green infrastructure projects? Or would it be better to spend project funding on relocating those who are most vulnerable? Therefore, to evaluate green infrastructure projects for disaster risk reduction, an evidence base could be developed to show that DRR project will have the intended outcomes for people as well the environment and infrastructure system. Table 2.2.2.1 shows what could be expected from implementing green infrastructure as DRR, but few projects have explicitly tracked quantifiable outcomes. One of the challenges of evaluating DRR projects is the difficulty in measuring social and ecological benefits, and their interactions with the intensity of the hazard. These challenges can be overcome with well-designed program implementation. Program evaluation should have capacity to take into account the social issues, hazard issues, and green infrastructure components.

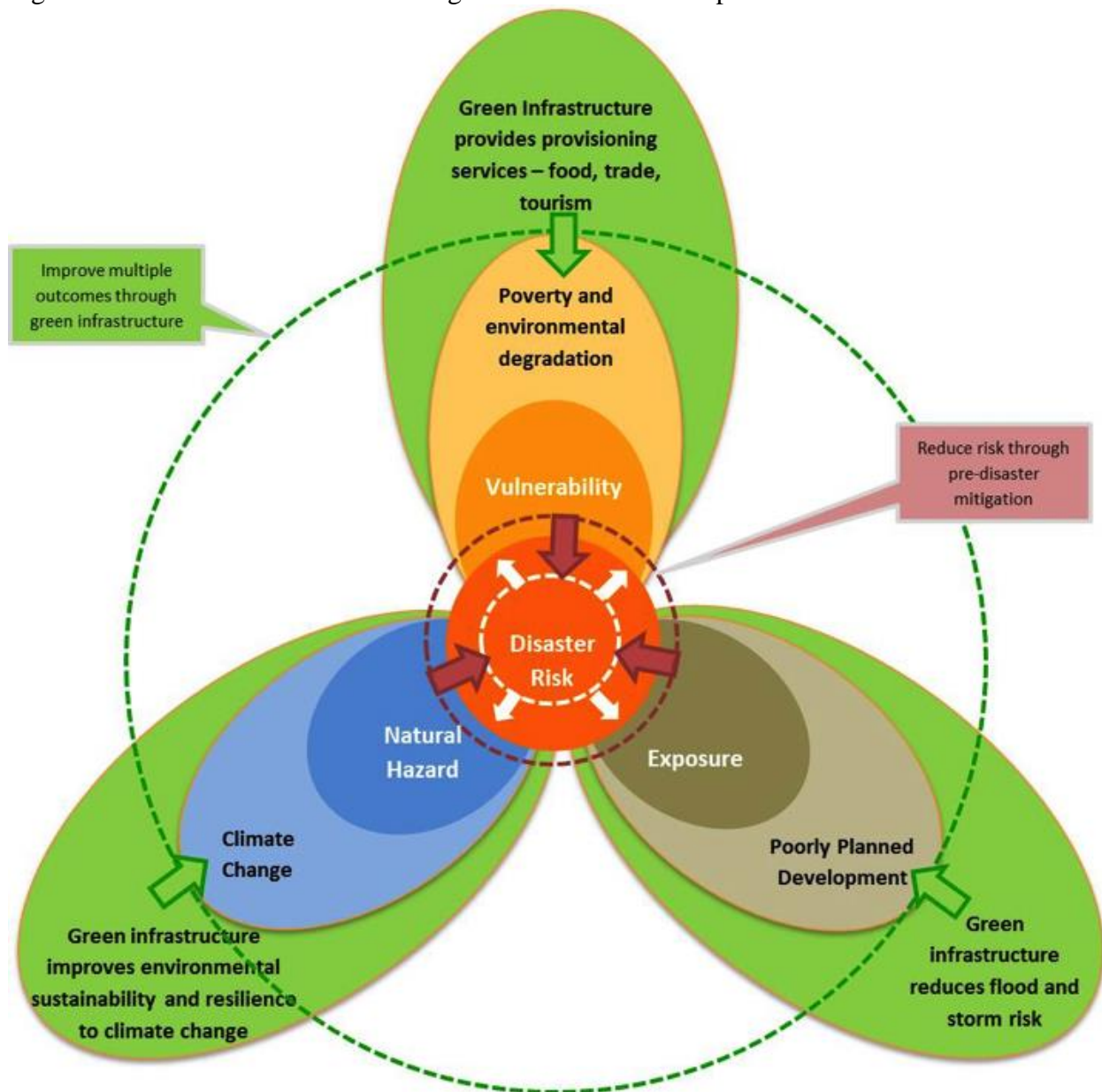
Figure 2.2.2.1. Anticipated Contributions of Green Infrastructure to Meeting Risk Reduction, Development, and Environmental Sustainability Outcomes.

Contribution of Green Infrastructure to Meeting Risk Reduction, Development and Environmental Sustainability Outcomes																								
Green Infrastructure Feature	Flood & Storm Risk Benefits									Development Benefits									Environmental Benefits					
	Ecosystem Service	Keep out of harm's way	Flood storage	Improve flood conveyance	Slow conveyance	Reduce flood stage	Reduce erosion and sedimentation	Reduce wave height		Protect drinking water	Provide food sources	Improve agriculture	Improve fisheries	Improve urban quality of life	Improve air quality	Improve forestry	Reduce water pollution		Conserve biodiversity	Improve water quality	Reduce sedimentation	Water temperature control	Carbon sequestration	
Conserving/restoring forests				+		+				+	+			+	+	+	+		+	+	+	+	+	
Conserving/restoring riparian lands/forests	+			+		+				+	+		+		+		+		+	+	+	+	+	
Reconnecting river to floodplains		+	+		+	+					+					+			+	+	+		+	
Conserving/restoring wetlands	+	+		+	+/-	+				+	+		+			+			+	+	+	+	+	
Constructing wetlands		+		+	+/-	+				+	+		+	+		+			+	+	+	+	+	
Establishing flood bypasses	+	+	+		+						+			+						+	+			
Fish/flood friendly culverts/bridges			+		+	+						+	+						+		+			
Establishing flood detention areas	+	+		+	+						+	+									+			
Establishing filter strips, grass waterways on tilled farm fields				+	+	+				+	+					+				+	+			
Building bioswales, rain gardens, stormwater recharge areas				+	+	+				+			+	+		+				+	+	+	+	
Conserving/restoring mangroves	+	+		+			+				+	+	+		+		+		+	+	+	+	+	
Conserving/restoring coastal marshes	+/-	+		+			+				+	+				+			+	+	+	+	+	
Conserving/restoring beaches and dunes	+			+			+						+						+					
Conserving/restoring coral and shellfish reefs							+			+		+				+			+	+				
Building living shorelines				+			+/-			+		+							+	+	+	+	+	
Conserving/restoring intertidal flats							+/-			+		+							+	+			+	

+ = usually, +/- = sometimes

Source: The Nature Conservancy 2015, p. 48.

Figure 2.2.2.2. Green Infrastructure targets reductions of multiple risk variables.



Source: The Nature Conservancy 2015, p. 9.

2.3 Definition of Mangroves and Their Benefits

2.3.1 Mangrove Definition

There are three definitions for mangroves: as a species, as a stand of the species, or as a community of vegetation. When mangroves, mangrove stands, mangrove forests, and mangrove ecosystems are mentioned, the implication here is as a community of vegetation.

2.3.2 Mangroves as Disaster Risk Reduction

Green infrastructure projects focused on flooding can be viewed as DRR projects, as they are used to reduce the impact of flooding on the built environment and the risk to vulnerable societies. One such green infrastructure project is mangrove restoration. A review of the eastern coast of India after the 1999 cyclone by Das and Vincent found that mangroves significantly reduced the number of deaths than would have been expected in certain areas (2009, p. 7539). In their statistical analysis, they found that mangrove vegetation is most important, rather than the width of the stand. With an economic analysis, Das and Vincent found that protecting mangroves is economical justified, especially when taking the goods, services and lives saved into account (Das and Vincent 2009, p. 7539). In another study, Zhang, et al. found that storm surge increased at the front of mangrove stands – therefore, damaging anything in front of mangrove stands – but decreased at the back end of mangrove stands compared to areas without mangrove habitat in Florida (Zhang et al. 2012, p. 17). These stands were able to protect freshwater marshes from a Category 3 hurricane, but would need to be much wider to reduce the impact of a Category 4 or 5 storm (Zhang et al. 2012, p. 22). Another study found that a mangrove stand with a width of 50 meters reduces one-meter waves to less than one-third of a meter, with a 150-meter width completely reducing the energy of a one-meter wave (GIZ 2013).

Evidence suggests that areas with mangrove forests may reduce flooding extent and associated damage from surges caused by storms and small to moderate tsunamis (Spalding, et al. 2014, p. 294). Mangroves provide enough protection to lessen the amount of damage compared to villages without a mangrove stand buffer (Tanaka 2009, p. 72). However, much of this is dependent on the magnitude of the energy reduction in a mangrove forest, which itself is dependent on “tree density, diameter of the trunks and roots, forest floor slope, the characteristics

of the incident waves, and the tidal stage at which the waves enter a forest” (Tanaka 2009, p. 75). Mangroves can provide tsunami mitigation by reducing tsunami energy before entering a river mouth (Tanaka 2009, p. 78), which is important in delta coastal management. Degradation of the mangrove stand from shrimp farms, industrial development, and tourism can make mangrove forests vulnerable, (Tanaka 2009, p. 76). Vermaat and Thampanya (2006) and Kathiresan and Rajendran (2005) found that mangrove forests mitigated tsunami damage in southeast India, though the extent of the benefit is debated, according to Kerr et al. (2005). Spalding et al. (2014) recommend avoiding exact predictions of hazard mitigation, but find that the combined benefits of multiple ecosystems, such as having reefs, marshes, and sand dunes in addition to mangroves, can increase risk reduction (p. 297). At the same time, mangrove stands can be helpful without reefs or sand dunes. An ethnobiological survey from Sri Lanka after the 2004 tsunami found that mangroves offered protection, but that forests degraded by clearance, insufficient regrowth, and excess non-mangrove components seemed less able to do so (Dahodouh-Guebas, et al. 2005, p. 445). Flood surge protection is dependent on quality of the mangrove stands. It also plays a factor in mangrove survival; intense flooding of either salt or freshwater can negatively impact mangrove stands (Bosire, et al. 2008, p. 255).

Cochard (2011) remains unconvinced of the disaster risk reduction potential of mangrove stands. Most accounts of disaster protection are anecdotal and there are several analyses that caution against these claims (Cochard 2011, p. 182). Often, evidence is given as post-hoc observational studies, anecdotes, remote sensing, and modeling (Cochard 2011, p. 182; Feagin, et al. 2010, p. 2). Instead, according to Feagin, et al. (2010), experimental evidence needs to be collected from the field to compare vegetated to non-vegetated areas (p. 3). It is also important to realize that after a surge event ecosystems are weakened and vulnerable to subsequent events,

and may not have enough time for sufficient recovery (Cochard 2011, p. 184). Despite the lack of experimental designs for the true life-protection value of mangroves, Cochard, and Feagin, et al. believe that mangrove coastal ecosystems provide very real social and economic benefits that contribute to the resilience of coastal communities (Cochard 2011, p. 180; Feagin, et al. 2010, p. 9). Further scientific study needs to be done on the true DRR potential of mangroves, especially as people's lives and livelihoods are at risk – the most important reason for implementing DRR projects. These studies should focus on the width and vegetation cover of the mangroves, the intensity of the storm, the impacts on infrastructure, how long it takes for people to return to their livelihoods, and the regeneration time for the mangrove ecosystem. This information could then be used to develop mangrove DRR projects where they would have the greatest impact and where they are most beneficial. These studies would provide a scientific understanding of when other projects may be more useful than utilizing mangroves.

2.3.3 Other Benefits of Mangrove Stands and Afforested Mangrove Stands

Research has been done on the additional benefits and ecosystem services of mangroves beyond flood reduction. Some of these include carbon sequestration, payments for carbon sequestration through REDD+, timber, and ecotourism (Tompkins, et al. 2013, p. 11, 13). Tuan and Tinh separated these benefits into use – direct and indirect – and non-use values, ranging from fishing, fuelwood collection, and recreation to nutrient retention, flood control, shoreline protection, and cultural heritage (see Table 2.3.1). The exact contribution of mangroves to fisheries is hard to estimate, though mangroves are widely thought to contribute to coastal fisheries either as a direct food source or as a nursery (Walton, et al. 2006, p. 339, 340). One study placed the economic value of mangroves for fisheries at USD 37,500 per hectare of mangroves (GIZ 2013).

Table 2.3.1. Total economic value of mangrove forests

Use Values			Non-use value
Direct use value	Indirect use value	Option value	
<ul style="list-style-type: none"> • Fishing • Agriculture • Fuelwood collection • Recreation • Transport • Harvesting wildlife • Peat/energy 	<ul style="list-style-type: none"> • Nutrient retention • Flood control • Storm protection • Groundwater recharging • External ecosystem support • Micro-climatic stabilization • Shoreline stabilization • Fish nurseries 	<ul style="list-style-type: none"> • Potential future uses (as per direct and indirect uses) • Future value of information 	<ul style="list-style-type: none"> • Biodiversity • Cultural heritage • Bequest values

Source: Adapted from Tuan and Tinh 2013, Table 2, p. 16.

These services can be important to local populations. In a survey of villagers in Nijhum Dwip Island, Bangladesh, respondents mentioned the supply of raw materials, natural disaster prevention, climate regulation, and soil retention as the most important features of mangrove forests (Iftekhar and Takama 2008, p. 129). In particular, mangroves have been able to maintain surface elevation in relation to rising sea level, dependent on the geologic setting (Spalding, et al. 2014, p. 295). This can be seen in the Sundarbans, where a large planting of mixed mangrove species has improved sediment deposition to the point where about 40 percent of the area has risen in elevation enough to make it no longer suitable for mangroves (Bosire, et al. 2008, p. 255).

A study completed in the Philippines estimated the initial planting costs for a stand of mangroves at US\$ 211 per hectare, though the total direct use value of the stand came to about US\$ 564 to US\$ 2,316 per hectare per year to the local community, stemming from fish production, tourism, and harvested timber (Walton, et al. 2006, p. 340-341). Although the returns seem large compared to the initial costs, the initial costs are prohibitive to the local community, which is why those with external funding often undertake mangrove restoration projects

(Walton, et al. 2006, p. 341; Bosire, et al. 2008, p. 255). A recent study done by the UNEP found that ecosystem services of mangroves amount to US\$ 33-57 thousand per hectare to the national economy of the country with the mangrove stands (van Bochove, et al. 2014, p. 8). This is a large difference, and one that should be further explored to better understand the value of this unique ecosystem.

It is also important to distinguish between restored, rehabilitated, and natural mangrove forests. Ellison (2000) focuses on this difference, finding that restored mangrove forests often resemble plantations, rather than ecosystems (p. 224). At the same time, these restored forests can be the first step toward rehabilitation, as low diversity plantings can give way to higher diversity forests, if they are not harvested (Ellison 2000, p. 225). This is a large caveat. Often, while the goal of mangrove restoration is to provide disaster risk reduction, the projects hope to provide other economic benefits, such as harvesting wood. Therefore, when looking at the cases under review in this paper, it is important to look at the goals of the project and what those mean for the regeneration of the mangrove stand and the benefit for local communities. Bosire, et al. (2008) found that stem densities are higher in restored mangroves than in natural stands (p. 252), but the biodiversity is lower in planted stands (p. 253). Overall, though, the greatest hindrance to biodiversity is the clearing and degradation of stands (Bosire, et al. 2008, p. 253).

3. Direct Human Impacts Causing Mangrove Stand Degradation and Destruction

Previous estimates put mangrove degradation and destruction at about half of their 1950 global extent. More recent estimates put the global loss of mangrove stands at about 12.3 percent less mangrove coverage than what had previously been estimated (Earth Observatory 2010). Of the stands that are left, much of it is degraded and law protects only 6.9 percent from further destruction (Earth Observatory 2010). Mangroves are being destroyed at rates 3-5 times greater

than average rates of forest loss (van Bochove, et al. 2014, p. 6). In Vietnam alone, about 180,000 hectare of mangrove forest have been converted to other purposes, including aquaculture, infrastructure, and urban projects (Tuan and Tinh 2013, p. 10). Mangroves in Bangladesh face human threats, with 40,000 hectares of natural and manmade forests destroyed along Bangladesh's eastern and central coasts (UNDP-Bangladesh 2008, p. 9). One of the main reasons for the destruction of this ecosystem is the increase in shrimp aquaculture.

While mangroves support wild fisheries, mangrove stands are being cut down to make way for agriculture, aquaculture, and urban growth. Using satellite imagery, Giri, et al. (2008) found that the major cause of mangrove deforestation in Southeast Asia is due to agricultural expansion (p. 523). Globally, though, major mangrove deforestation and degradation stems from aquaculture production (van Lavieren, et al. 2012, p. 13). The policy brief *Securing the Future of Mangroves* argues that shrimp farming is a particular problem for Southeast Asia (van Lavieren, et al. 2012, p. 14). This is especially true in more recent years, as shrimp farming is expanding at a faster rate than other coastal land uses, particularly in southern Vietnam (Thu and Populus 2007). Shrimp is now the number one seafood consumed in the U.S., replacing tuna, with much of the shrimp farmed in Asia exported to the U.S. and Europe (Greenway 2012). About one-third of the global mangrove coverage is found in Southeast Asia, with more than a quarter of the mangrove loss from 1980 to 2005 coming from this region (van Lavieren, et al. 2012, p. 11). In Tuan and Tinh's (2013) cost benefit analysis of mangrove restoration in Vietnam, their two hypothetical land uses to be analyzed were mangrove restoration or shrimp aquaculture development, as they believe the two are dichotomous and cannot be combined (p. 17). This distinction between alternative land uses is important because it puts ecosystem benefits from mangroves in direct conflict with social benefits gained from potentially improved livelihood

options. While coastal delta regions are in a state of transition to numerous land uses, this paper focuses specifically on the protection and rehabilitation of mangroves in the face of conversion pressures for improved livelihood opportunities, such as shrimp farming.

There are several ways that shrimp farming negatively impacts mangrove ecosystems. In Bangladesh, some shrimp farmers catch larvae, keeping only the shrimp fry to grow in their shrimp ponds – destroying other larvae in the process (Greenway 2012). While Bangladesh has outlawed the practice, it is not enforced. These farmers often use toxic chemicals to destroy other organisms to provide space for the shrimp (Greenway 2012). Mangrove stands provide nurseries for many fisheries, including shrimp. However, mangrove stands are removed to make way for shrimp ponds, destroying the nurseries for wild shrimp and many other species (Greenway 2012). Many species of fish and crustaceans start their lives amongst the roots of mangroves, while the canopy provides habitat for land animals; the destruction of these stands negatively impacts other fisheries and wildlife (Greenway 2012), even though it can bring in large sums of money. Locals in Vietnam feel that freshwater crops, such as rice, are lower risk and more stable than shrimp farms, yet are willing to make the switch to shrimp due to the high income generation potential (Troeh 2014).

Yet shrimp farming is not always in conflict with mangrove forest stands. For example, as shrimp farming expands, so has organic shrimp farming. In Vietnam, there is only one large certified organic shrimp supplier, Camimex. It is labeled as organic because it does not use antibiotics, fertilizer, or chemicals, and works to preserve mangrove habitat (Stewart 2015). Naturland Certification standards also addresses mangrove reforestation, where shrimp farms need to reinstate at least 50 percent of the mangrove forest that existed prior to the farm's creation (Ha, et al. 2012, p. 635). Under provincial guidelines for certification in Vietnam, only

40 percent of the original stand must be restored (Ha, et al. 2012, p. 636). However, of Camimex's 10,000 tons of annual production, only 20 percent comes from organic aquaculture (Stewart 2015).

This certification does not consider other important factors that impact the health of mangrove stands. For example, creating ponds near the shoreline can negatively impact mangrove stands as these ponds often alter the freshwater-saltwater hydrologic balance that the stands depend on (Greenway 2012; Troeh 2014). Once saltwater is allowed into a freshwater area, it is hard to bring the balance back (Troeh 2014). In addition, the patchwork system of mangroves might not have the same wave reduction potential as an integrated stand, which is an important consideration if mangrove projects are implemented with resilience and risk reduction in mind. While the Naturland Certification is well intentioned, it may not produce the same quality of stands that existed before.

Section 2.3 showed the direct benefits of mangroves to local communities and in reducing the risk of disaster in the event of a cyclone. Shrimp farming and other land use changes have the potential to bring in other kinds of benefits, such as improved livelihoods through increased income. The social-ecological systems framework can be used as a diagnostic to inform the design of these projects, given multiple actors and users. Understanding these design principles helps to make these projects successful, especially when there may be pressure to develop the coasts to provide other livelihood benefits, such as pressure to convert the land to shrimp farming.

4. Methodology: Social-Ecological Systems Framework

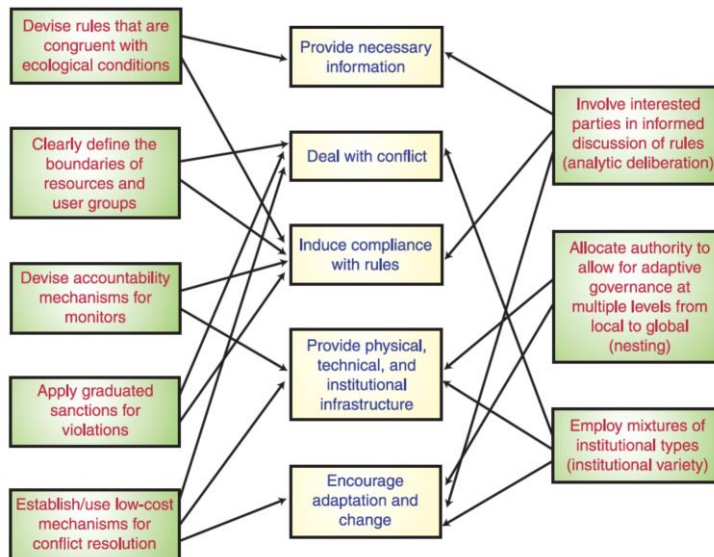
4.1 Eight Principles for Governing the Commons as an Initial Screen

The principles for robust governance of environmental resources (Dietz, et al. 2003, p. 1907) are applicable to studying and comparing the two mangrove cases in this paper. The principles are based on Dr. Ostrom's eight principles for governing common pool resources (Dietz, et al. 2003, p. 1910). Examples of common pool resources include shared grazing areas, irrigation systems, forests, and fisheries (Cinner, et al. 2013, p. 1360). These general principles are the result of multiple studies focusing on sustainable, resilient management of SESs. Seen in Figure 4.1.1, these general principles provide best practices for organizations to implement when designing interventions to address common pool resource issues.

These eight general principles are for robust governance of environmental resources: 1) clearly define the boundaries of resources and user groups; 2) devise rules that are congruent with ecological conditions; 3) devise accountability mechanisms for monitors; 4) apply graduated sanctions for violations; 5) establish/use low-cost mechanisms for conflict resolution; 6) involve interested parties in informed discussion of rules (analytic deliberation); 7) allocate authority to allow for adaptive governance at multiple levels from local to global (nesting); and 8) employ mixtures of institutional types (institutional variety). These combine to meet the five requirements for adaptive governance, shown in the pale yellow boxes. If a system has all eight general principles, chances are it will have more adaptive governance strategies that are locally, instead of internationally, based (Dietz, et al. 2003, p. 1910). These principles can be used as a first screen for the projects; if a project does not meet these principles, chances are the project is not sustainable or resilient over the long run. This is a good way to evaluate projects quickly. If a

project meets these principles, it will be easier to use the SES diagnostic framework and see which variables may be most important for other, future projects to meet the desired outcomes.

Figure 4.1.1. General principles for robust governance of environmental resources



Source: Adapted from Dietz, et al. 2003, p. 1910, Figure 3

4.2 Defining the SES Diagnostic Framework

A deeper way to analyze the use of coastal areas for mangrove restoration is through a social-ecological systems (SES) diagnostic framework. There have been multiple definitions and applications of SES over the last few decades, including the flow of energy from nature into society; an earth systems approach that distinguishes between geo-, bio-, and human spheres; and linked subsystems to see how to create sustainable and resilient outcomes (Glaser and Glaeser 2014, p. 2040-1). The diagnostic approach for understanding the sustainability of common pool resources through SES was developed by Ostrom and has been updated in more recent years (McGinnis and Ostrom 2014, p. 30). This diagnostic framework looks at the interactions of natural resource use, the ecosystem, people, and government structures to understand how common pool resources are used and where interventions can be made to manage them more effectively (Ostrom 2007, p. 15181).

Ostrom built the SES diagnostic framework off the eight principles covered in 4.1 and the institutional analysis and development (IAD) framework (McGinnis and Ostrom 2014, p. 31). At the center of the IAD and the SES diagnostic framework is the action situation where individuals interact with each other and affect outcomes (McGinnis and Ostrom 2014, p. 31). The SES diagnostic framework was created in 2007 in a collaboration with members of Resilience Alliance (McGinnis and Ostrom 2014, p. 30) to build a “common vocabulary and structure” to facilitate communication and accumulate knowledge about what works best in managing different common pool resource situations (McGinnis and Ostrom 2014, p. 30; also Ban, et al. 2013, p. 197; Cinner, et al. 2013, p. 1360). A framework, or conceptual map, was created because of the number of diverse processes occurring in the SESs (McGinnis and Ostrom 2014, p. 31; Ostrom 2007, p. 15182).

The framework is comprised of decomposable systems, seen in Figure 4.2.1 and Table 4.2.2, which means the SESs can be partitioned (Ostrom 2007, p. 15182). These subsystems are independent of each other in terms of the functions they have, but they affect the performance of the other – also known as parallel functionality (Ostrom 2007, p. 15182). The combination of the systems also creates differences that are stronger than if the systems were taken separately (Ostrom 2007, p. 15182). The framework is a combination of nested conceptual maps, which creates a starting point for analyzing social-ecological systems. The eight top-tier subsystems of the SES are social, economic and political settings (S); resource systems (RS); resource units (RU); governance systems (GS); actors (A); interactions (I); outcomes (O); and related ecosystems (ECO) (Ostrom 2009, p. 421; Cinner, et al. p. 1361). These are broken down into second-level variables, as seen in Table 4.1.2, and these can be further split into third-, fourth-, and fifth-tier variables. Not all variables are needed each time (Ostrom 2007, p. 15186). In the

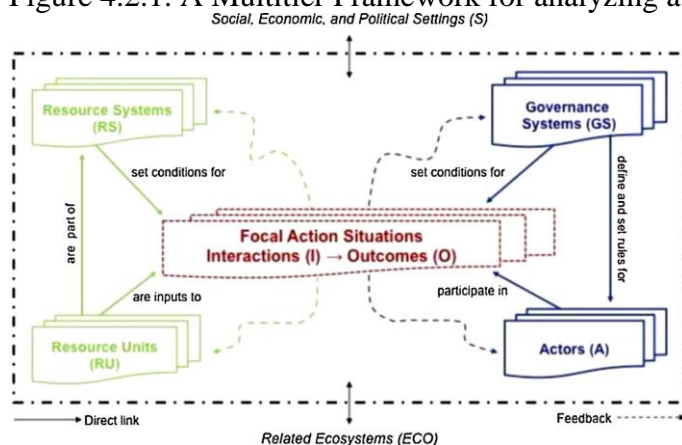
case studies in Sections 5 and 6, only second tier variables are used for ease of understanding across cases. The SES diagnostic framework shown in Figure 4.2.1 and Table 4.2.2 is the most up to date version of what Ostrom proposed in 2007, after she made changes in 2009 and 2014 (McGinnis and Ostrom 2014). It is important to recognize that the framework continues to evolve over time.

This framework is used to answer broad research questions, including what interactions and outcomes result from what rules of governance and resource system use, what are the likely changes to the system with or without external financial pressure or rules, and how sustainable the system is in the face of disturbances (Ostrom 2007, p. 15182). The SES view emphasizes the “unpredictable, dynamic, and evolved nature of linked social and ecological systems” (Ban, et al. 2013, p. 196). The long-term goal of the framework is to find which combination of variables leads to relatively sustainable and resilient use of a particular resource system (Ostrom 2007, p. 15183). The framework provides a way to study and record the unintended effects of particular policy interventions so that dangerous – or beneficial – combinations of policies can be avoided – or used (Ostrom 2007, p. 15186). In addition, it can help in establishing what components are relevant to a given study of the SES, while maintaining the multi-level structure of the problem under focus (Cinner, et al. 2013, p. 1362). These help to make SES problems tractable because, while cases are unique, this framework provides a set of elements that can help explain success or failure in common pool resource management.

There are several important weaknesses to this framework that should be mentioned. The original SES framework Ostrom created, before the development of the SES diagnostic framework, was a list of conditions and did not address resource characteristics (Agrawal 2001, p. 1655). However, it now incorporates more variables and conditions, which causes new

complexities. It often is challenging to know all the variables, which can hinder understanding the potential outcomes (Ostrom 2007, p. 15183). Funding a detailed comparison, being able to afford the measuring of all the variables, is a challenge (Agrawal 2001, p. 1665). The framework itself, while it does have multitier variables, is focused on local systems, while the governance of environmental systems is affected by cross-scale problems (Lemos and Agrawal, p. 308). The region can be used as a focal point because it provides more options for interface – from regional up to national up to global, and from regional down to local communities (Glaser and Glaeser 2014, p. 2043). Another problem lies in the gaps in knowledge of the groups and communities portrayed, but also of those who use SES framework tools (Agrawal 2001, p. 1657-8). It should not be used as a blueprint for the solutions, but instead as a learning process (Ostrom 2007, p. 15181). The problem lies in certain perspectives or types of studies being minimized by those that use this framework, which could possibly lead to incorrect assumptions and the wrong proscription (Cinner et al. 2013, p. 1362). Another weakness is that the framework does not include ecosystem services, though some would argue that it is included in the resource units variables. Future research on incorporating more ecosystem services in the framework could be helpful.

Figure 4.2.1. A Multitier Framework for analyzing a social-ecological system



Source: Adapted from Cinner, et al. 2013, p. 1361, Figure 1; McGinnis and Ostrom 2014, p. 33, Figure 2.

Table 4.2.2. Second-tier variables in framework for analyzing a social-ecological system

Social, Economic, and Political Settings (S)	Related Ecosystems (ECO)
S1: Economic development S2: Demographic trends S3: Political stability S4: Other governance systems S5: Markets S6: Media organizations S7: Technology	ECO1: Climate patterns ECO2: Pollution patterns ECO3: Flows into and out of focal SES
Resource Systems (RS)	Governance Systems (GS)*
RS1: Sector RS2: Clarity of system boundaries RS3: Size of resource system RS4: Human-constructed facilities RS5: Productivity of system RS6: Equilibrium properties RS7: Predictability of system dynamics RS8: Storage characteristics RS9: Location	GS1: Government organizations GS2: Nongovernment organizations GS3: Network structure GS4: Property-rights systems GS5: Operational-choice rules GS6: Collective-choice rules GS7: Constitutional-choice rules GS8: Monitoring and sanctioning rules
Resource Units (RU)	Actors (A)
RU1: Resource unit mobility RU2: Growth or replacement rate RU3: Interaction among resource units RU4: Economic value RU5: Number of units RU6: Distinctive characteristics RU7: Spatial and temporal distribution	A1: Number of relevant actors A2: Socioeconomic attributes A3: History or past experiences A4: Location A5: Leadership/entrepreneurship A6: Norms (trust-reciprocity)/social capital A7: Knowledge of SES/mental models A8: Importance of resource (dependence) A9: Technologies available
Action Situations – Interactions (I)	Action Situations – Outcomes (O)
I1: Harvesting I2: Information sharing I3: Deliberation processes I4: Conflicts I5: Investment activities I6: Lobbying activities I7: Self-organizing activities I8: Networking activities I9: Monitoring activities I10: Evaluative activities	O1: Social performance measures O2: Ecological performance measures O3: Externalities to other SESs

*Alternative Second Tier GS	Third tier variables
GS1: Policy area GS2: Geographic scale of governance system GS3: Population GS4: Regime type	

GS5: Rule-making organizations	Public sector organizations
GS6: Rules-in-use	Private sector organizations
GS7: Property-rights systems	Nongovernmental, nonprofit organizations
GS8: Repertoire of norms and strategies	Community-based organizations
GS9: Network structure	Operational-choice rules
GS10: Historical continuity	Collective-choice rules
	Constitutional-choice rules

Source: Adapted from Cinner, et al. 2013, p. 1361, Table 1; McGinnis and Ostrom 2014, p. 34, Table 1 and pg. 38, Table 2.

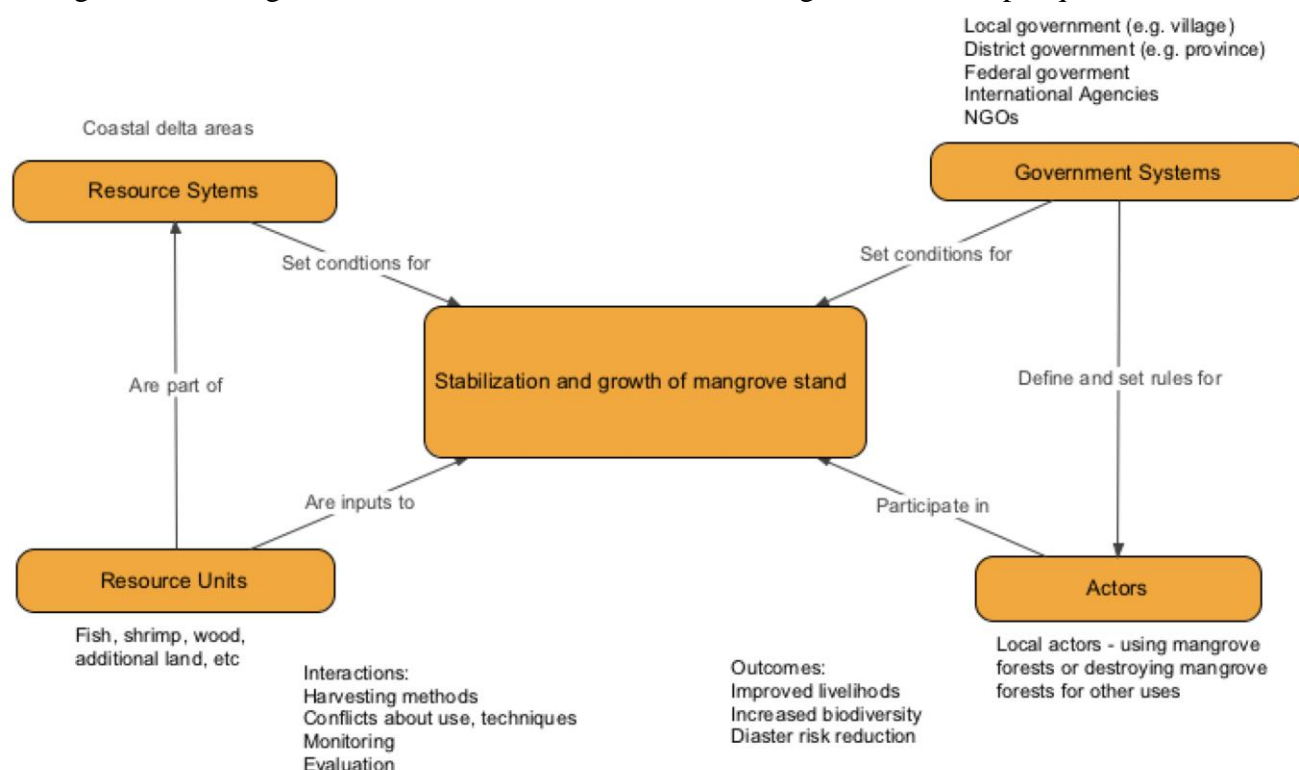
Despite these weaknesses, the SES diagnostic framework is useful in drawing common lessons from different cases (Cinner, et al. 2013, p. 1359). It has been used to draw comparisons across successful sustainable fisheries cases and in conservation studies to determine the most effective strategies for management (Cinner, et al. 2013; Ban, et al. 2013, p. 197). At the center of the framework, the “focal action” situation leads to proposed actions and outcomes that can be evaluated in light of stakeholders’ opinions and beliefs (Ban, et al. 2013, p. 197). Therefore, this framework could be used to examine mangrove stands used for green infrastructure purposes to determine which implementation strategies are most effective.

4.3 SES Diagnostic Framework: Coastal Management for Improved Mangrove Stands

The problems of overharvesting and misuse of ecological systems are rarely attributable to a single cause (Ostrom 2007, p. 15181), and the same is true with the management of coastal ecosystems. Shrimp farming is not the only problem; it is a problem of providing improved livelihood opportunities. For mangrove stands to be considered an ideal use of coastal area land, they need to provide similar potential for income generation as shrimp and agricultural opportunities, or allow for mixed uses. While each coastal village is different, and panaceas should not be prescribed (Cinner, et al. 2013, p. 1363), the overall mangrove restoration or stand SES diagnostic framework might look like Figure 4.3.1.

Figure 4.3.1 is basic and only uses first-tier variables, with no well-defined actors or government systems, and only loosely defined second-tier variables. To better understand how the SES diagnostic framework can be applied to mangrove projects, cases from Vietnam (Section 5) and Bangladesh (Section 6) are used. The focus is on cases from these two countries as these countries face significant climate change challenges, especially in their coastal regions. At the same time, these countries are experiencing mangrove losses as local people develop the area for other projects, including shrimp aquaculture, as described in Section 3. The SES diagnostic framework is applied in order to: 1) understand how the social and ecological systems interact with each other to develop desired outcomes and 2) compare the projects in Vietnam and Bangladesh.

Figure 4.3.1. Diagnostic Framework for Coastal Area Mangrove vs. Shrimp Aquaculture



Source: Based on the diagnostic framework from Cinner, et al. 2013; McGinnis and Ostrom 2014.

5. Case from Vietnam: Management of Natural Resources in the Coastal Zone of Soc Trang Province

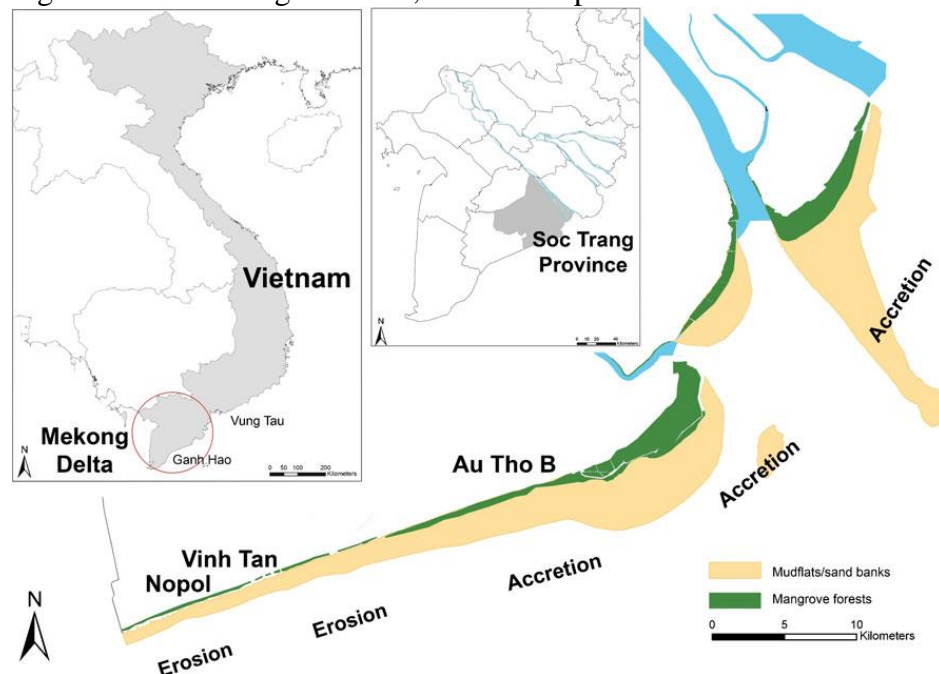
The “Management of Natural Resources in the Coastal Zone of Soc Trang Province” project was funded by the German Federal Ministry of Economic Cooperation and Development, and implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), with cooperation from the Soc Trang Provincial People’s Committee. The project lasted for a period of five years, from 2007 to 2012, though the effects persist after this time (ci:grasp n.d.). The project has a main goal of protecting and sustainably using the coastal wetland of Soc Trang Province for the benefit of the local population (Lloyd 2010, p. 14). The project involves multiple pilot projects, methods, and trainings, coming to a total cost of EUR 3.2 million (ci:grasp n.d.). This project is important because the coastal areas face a variety of climate change concerns, including sea level rise, saline intrusion, increased storm intensity, higher rainfall during the rainy season, and floods (Schmitt 2009, p.4).

The project has focused on rehabilitation and management of mangroves with an emphasis on resilience to climate change and related livelihoods (Lloyd 2010, p. ii; Schmitt 2009, p.6). The province includes a total population of 1.2 million people, with three main ethnicities – Kinh (Vietnamese), Hao (Chinese-Vietnamese) and Khmer (Lloyd 2010, p. 16). The ratio of people from each ethnicity varies from district to district and village to village. For this project, the focus was on the three coastal districts of Cu Lao Dung, Long Phu, and Vinh Chau, with a total coastline of 72 km. Each village within each commune within each district of the province has its own coastal management challenges. For example, in Tan Nam, many locals blame shrimp farming and storms for loss of mangroves, whereas in Au Tho B the mangrove stand has been growing due to support from a previous project and is only now starting to feel encroachment on these stands by shrimp farmers (PanNature 2010, p. 41-43). Some areas are

experiencing erosion, while others have sediment accumulation (Schmitt, et al. 2013, p. 546).

The entire area covered by the project can be seen in Figure 5.1.

Figure 5.1. Soc Trang Province, location of pilot sites and accretion/erosion areas



Source: Schmitt, et al. 2013, p. 546, Figure 1.

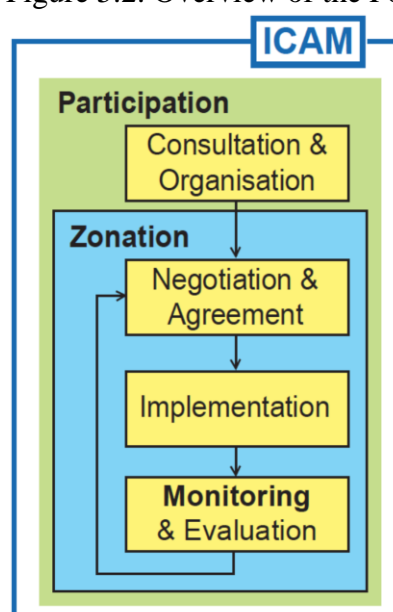
Co-management is one of the management strategies being tested by this project. Co-management is based on contracts made between groups of people rather than individuals to work with authorities to share management and responsibilities for a set of natural resources or an area of land (Lloyd 2010, p. 14). There are four steps to co-management:

- 1) Consultation and organization, using surveys and capacity-building activities
- 2) Negotiation meetings to create formal agreement between authorities and resource users
- 3) Implementation of the negotiated agreement
- 4) Monitoring and evaluation to provide feedback for re-negotiations (Lloyd 2010, p. 12-13)

The principles include: integrated coastal area management (ICAM), participation, zonation, and monitoring (Lloyd 2010, p. 23). In ICAM, resources are viewed from an ecosystem perspective, not just site specific, as adjacent sites may interact with the specific site (Lloyd 2010, p. 24). All

stakeholders need to be involved, as any exclusion will weaken the negotiated agreements (Lloyd 2010, p. 24). Zonation is the demarcation of different areas to receive various management regimes (Lloyd 2010, p. 24). Monitoring is both a principle and a step. These steps and principles interact together during the process, as seen in Figure 5.2. Benefits of co-management include effective protection, livelihood improvement through sustainable use, and involvement of resource users in decision-making (Lloyd 2010, p. 26).

Figure 5.2. Overview of the Four Steps and Four Principles of Co-Management Processes



Source: Figure 5 from Lloyd 2010, p. 25.

The village of Au Tho B is the pilot site for using these co-management principles. Other management techniques are using other management strategies to provide potential management solutions as part of this project (Schmitt 2009, p. 4). The village has 2.76 kilometers of coastline, a population of 3,638 people in 727 households of predominately Khmer and Hao ethnicities (Lloyd 2010, p. 12). Many of the residents are poor and rely on the coastal zone as their main source of income (Lloyd 2010, p. 12). However, in Vietnam, Prime Minister's Decision 116 creates restrictions for resource use (Lloyd 2010, p. 20). This Decision creates set zones along coastal areas. Zone 1: Full Protection is the mangrove forest area. In this zone, people are not

allowed to cut down trees, collect live vegetation, fish commercially, or hunt (Lloyd 2010, p. 20-21). Zone 2: The Buffer lies between the mangrove forest and the dike. In this zone, 60 percent of the land is reserved for mangrove forest development, while the rest may be used as agricultural land (Lloyd 2010, p. 21). Zone 3: The Economic Zone, falls between the dike and the main road and has no restrictions on development (Lloyd 2010, p. 21). As the Khmer tend to live closer to the coast (PanNature 2010, p. 15), this Decision has a larger impact on their lives.

Evaluation of the pilot in Au Tho B found that co-management appears to be working at this time, as seen by the increase in aquatic resources around the village (Schmitt, et al. 2013, p. 554). While this project increases natural resources for local use, the people's understanding of the importance of mangroves may be lacking (PanNature 2010, p. 49). Local people are aware of the importance of mangroves for their direct use values, but have trouble recognizing the other economic values that come from mangroves (PanNature 2010, p. 47). The provincial and district authorities that were interviewed tended to recognize added benefits and use values from mangroves (PanNature 2010, p. 25), though these individuals were better educated, predominately male, and Kinh (native Vietnamese) (PanNature 2010, p. 25). This points to broader social inequities that this project does not address. Supporting educational initiatives, instead of green infrastructure projects, could improve livelihoods and resiliency for those most at risk, and should be considered if the main goal is development and other beneficial outcomes.

Another problem that arose was a lack of involvement from shrimp farmers. Most shrimp farmers refused to meet and be interviewed (PanNature 2010, p. 38). Lack of cohesion and participation of all stakeholders may prevent the hoped for outcome of stabilization and growth of the mangrove stand. Finally, this particular project does not include livelihood training

(PanNature 2010, p. 47), which could be beneficial in improving the social resilience of individuals.

5.1 Clearly Defined Boundaries

The resource user groups and local authorities agreed that members should have membership cards to use for identification when collecting resources in the mangrove forest (Lloyd 2010, p. 52). The resources to be monitored were defined in negotiations, with set geographic boundaries for reporting collection.

5.2 Rules Congruent with Ecological Conditions

The users adapted monitoring to fit local knowledge. Rules were created to allow resources to grow, while allowing sustainable levels of harvesting (Lloyd 2010, p. 46-51). In addition, as harvesting levels were hard to quantify, the groups negotiated harvesting methods instead, to protect the most sensitive resources (Lloyd 2010, p. 51).

5.3 Accountability Mechanism for Monitors

Resource user groups came together to decide how various aquatic resources should be protected, monitored, and evaluated (Lloyd 2010). However, while the monitoring sheets were created, the user groups have not created an accountability mechanism.

5.4 Graduated Sanctions for Violations

There are graduated sanctions for violations. For the first offense of violating the agreements, the resources will be confiscated, and the offender will be suspended for three months, and will be subject to education lessons. For the second offense, the resources will be confiscated and the offender and his or her family will be suspended from using the resources for three months. On the third offense, the offender may have their membership terminated. For further offenses, or if the individual is not from Au Tho B's co-management group, the offender

will be dealt with by the local authorities (Lloyd 2010, p. 87). It is not clear what the graduated sanctions are for cutting down live mangroves.

5.5 Low-Cost Mechanism for Conflict Resolution

There have been a few problems with people outside the village coming in and using resources under Au Tho B's management (IUCN 2010). Within the village, resource user groups have used negotiation and signed agreements for conflict resolution.

5.6 Informed Discussion of Rules by Interested Parties (Analytic Deliberation)

Leadership training courses for local leaders and dual language use aided the progress of facilitation (Lloyd 2010, p. 34, 62). Stakeholders were highly involved throughout all steps, as they are the ones who use the resources. People from the local community determined strategies for action and set the boundaries (Lloyd 2010, p. 56). In addition, the resource user groups suggested using more efficient wood stoves (Lloyd 2010, p. 61). This has helped to reduce wood consumption and some illegal clearing.

5.7 Allocate Authority for Adaptive Governance (Nesting)

Schmitt, et al. (2013) found that ownership in joint governance and political support are the key factors for success (p. 555). In Au Tho B, governance of the aquatic resources has multiple layers, ranging from the leaders of the resource user groups, to the local government authorities, to the provincial authorities, to the federal government (Lloyd 2010, p. 13). The adaptive governance (nesting) principle extends out to the global level, but that is missing in this context. Yet there is some nesting present, with authority clearly demarcated.

5.8 Mixture of Institutional Types (Institutional Variety)

To maintain natural resource values, the co-management plan in Au Tho B includes payments from the clam cooperative to the resource users that protect the mangrove forests, as

the mangroves are helping to expand clam population (Schmitt, et al. 2013, p. 555). These payments are written into the negotiated agreement so that they are binding. Also, the government pays landowners to maintain forests by the hectare (Schmitt 2009, p. 7). Beyond payments, the co-management groups include rules for management, including harvesting method, and suspending members that do not follow rules.

5.9 SES Diagnostic Framework

This project followed seven of the eight design principles (see Dietz, et al. 2003; Section 4.1), creating space for adaptive governance, which helps increase resiliency of the SES. By going into more detail, specific variables and interactions can be evaluated and taken for use in other projects. Using evidence from the project materials, the SES diagnostic framework for the Au Tho B project component is summarized in Figure 5.9.1 and Table 5.9.2. While the program materials do not currently measure all of these indicators or variables, these are variables that are mentioned in the reports of the “Management of Natural Resources in the Coastal Zone of Soc Trang Province” project in Au Tho B village. These variables have interacted in a way to promote a system that is growing and improving the health of the mangrove stand. The mix of government systems in a co-management approach, which paired with well-defined ecosystem boundaries, has worked to reach the desired focal action. Not only that, the project has increased the number of resources. However, there could be conflicts in the future when the negotiated agreements expire.

Figure 5.9.1. SES Diagnostic Framework for “Management of Natural Resources in the Coastal Zone of Soc Trang Province” project’s Au Tho B village component

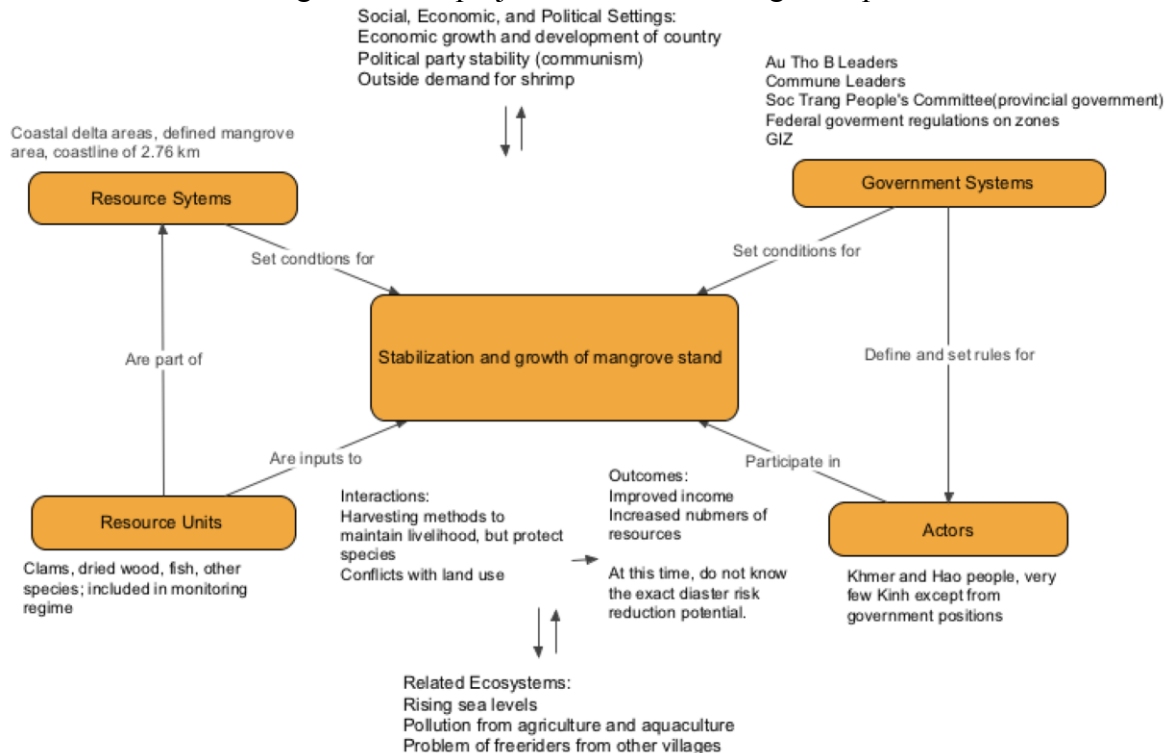


Table 5.9.2. Second-tier diagnostic variables for “Management of Natural Resources in the Coastal Zone of Soc Trang Province” project’s Au Tho B village component

Diagnostic framework components	Indicators	Description
S1: Economic Development	Improved Income Livelihood changes	Improved income, especially of people in Zone 2
S3: Political stability	Political Party Leadership	Soc Trang People’s Committee remains in place
S5: Markets	Outside demand for shrimp Outside demand for other aquaculture products	Impacts how the land might end up being used
ECO3: Flows in and out of focal SES	Outside users	Freeloaders situation, if it continues
RS1: Sector	Land management Mangroves	Area of each zone
RS2: Clarity of system boundaries	Strong definition	Co-management agreement sets boundaries for the managed zones
RS3: Size of the resource system	Area of each land use sector	Related to RS1
RS5: Productivity of system	Production of different aquatic species	Several reports have found increases in resources – tied to RU5

RS9: Location	Geographic Location	Where the specific system is within the zone
GS1: Government organizations	Who they are and how they related to the management	Soc Trang People's Committee at province level District and Commune stakeholders involved GIZ from Germany
GS4: Property Rights	Zone use defined by government	Area of zones set by the federal government of Vietnam
GS5: Operational-choice rules	Types of rules	Harvesting method, not amount harvested
GS6: Collective-choice rules	Participation in decision making	Co-management requires involvement of resource users
GS8: Monitoring and sanctioning rules	Monitoring sheets	Created by the negotiation process, used to monitor
RU4: Economic value	Value of the unit	Price of the resource
RU5: Number of units	Number of the units	Whether the resource is decreasing or increasing in number
A1: Number of actors	Number of people in system	Well-defined in Au Tho B
A2: Socioeconomic attributes	Ethnic groups	Ethnic groups have distinct economic and sector differences in this region
A7: Knowledge of SES	Understanding interactions, measure by interviews	At present, have poor knowledge of interactions of mangroves to use values
A8: Importance of resource (dependence)	Livelihood reliance ratio	How many actors rely on this coastal zone for livelihood
I1: Harvesting	Amount collected	Can reflect how sustainable the collection is over time
I2: Information sharing	Outcomes from management strategies	Assist in understanding best management strategies for coastal zones
I4: Conflicts	Differences in wanted use between groups	Measure based on differences with shrimp farmers
I9: Monitoring activities	What has happened with the resource	Monitoring determined by the resource users via negotiated agreement
I10: Evaluate activities	What activity works best	Which strategies are having the best impact
O2: Ecological Performance	How resource is improving, specifically mangroves	Mangroves tied to benefits in many aquatic sectors, so improvements here will most likely mean improvements for ecological system of the site

Source: Adapted based on MacNeil and Cinner 2013, p. 1395, Table 1

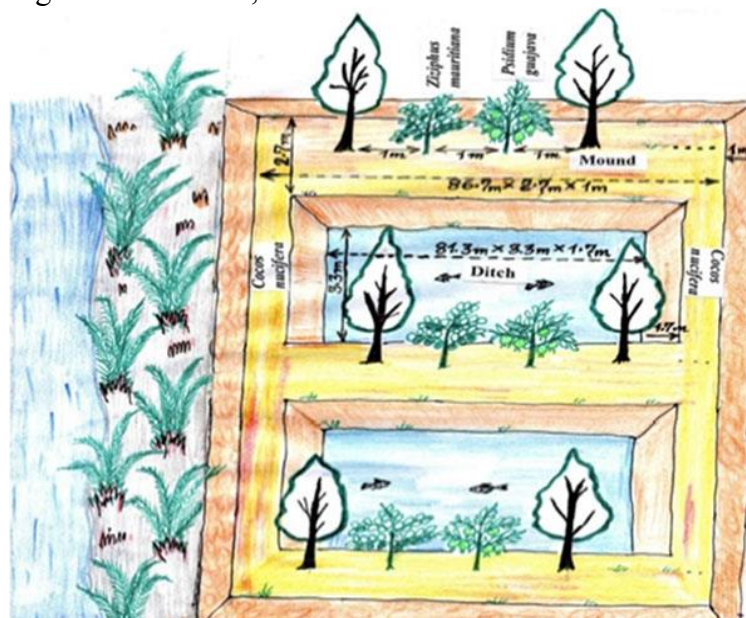
6. Case from Bangladesh: Community-based Adaptation to Climate Change through Coastal Afforestation

The “Community-based Adaptation to Climate Change through Coastal Afforestation” project in Bangladesh received funding from numerous agencies, including the Global Environmental Facility (GEF), United Nations Development Programme (UNDP), Government of Bangladesh (GoB), Swiss Development Cooperation (SDC), and Embassy of the Kingdom of the Netherlands (EKN). A majority of the project’s total cost of USD 8.55 million (about 6.75 million Euros in 2013) came from GEF, SDC, and UNDP (CBACC-CF Project 2014). The original project included funding of USD 5.4 million (UNDP-Bangladesh 2008, p. i) from fewer partners, so the project has grown in funding scope since its inception. The goal of the project is to reduce vulnerability in several coastal districts in Bangladesh: Barguna, Patuakhali, Bhola, Noakhali, and Chittagong (UNDP-Bangladesh 2008, p. ii). The project involves a four-prong approach for reducing vulnerability of communities and ecosystems in these coastal zones. These include 1) community-based adaptation measures to assist in livelihood diversification; 2) strengthened institutional capacity by incorporating climate risk reduction in coastal zone development; 3) future assessment of policy framework and development of recommendations; and 4) sharing of gained knowledge from the project through the UNDP Adaptation Learning Mechanism (UNDP-Bangladesh 2008, p. 17). This is important as these coastal areas are experiencing a rise in sea level, increasing temperatures, and an increased risk of storms (UNDP-Bangladesh 2008, p. 3-6). The agricultural and aquaculture sectors are sensitive to climate change, so improving livelihood opportunities in coastal regions, which rely heavily on these sectors, is vital (UNDP-Bangladesh 2008, p. 5).

The project involved five ways of implementing mangrove afforestation techniques. Seedling survival rates vary greatly across the methods, mostly due to site-specific

complications, such as increased wave action and differences in soil properties (UNDP-Bangladesh 2015, p. 13). Of the techniques used, the most interesting for the SES diagnostic framework is the “Forest, Fruit, Fish” (3F) model (see Figure 6.1). In this model, mangroves are planted on a mound along the coast. Behind the mangroves, the fallow area is developed into 60-meter long ditches with 3-meter wide ditches, which are for vegetable, fruit, and fish production (UNDP-Bangladesh 2014, p. 13). Each hectare is able to fit eight to ten families (UNDPP-ALM 2011). The government controls this land, but households are given ten-year leases to the land with renewal opportunities depending on beneficiaries’ performance (UNDP-Bangladesh 2014, p. 13).

Figure 6.1. “Forest, Fruit” Fish model schematic



Source: Rawlani and Sovacool 2011, p. 859, Figure 8.

This system provides multiple benefits and uses different crops, providing resilience if one species were to fail. Households consume the fish, vegetables, and fruits they grow, selling any excess. The sale of this excess food brings in additional income to the household, ranging from USD 1000 (UNDP-ALM 2011) to more recent estimates of USD 600-700 (UNDP-Bangladesh 2014, p. 13) annually. In either case, though, this is strong evidence that it improves

the livelihood potential of these coastal households. In regular livelihood capacities, the annual per capita income averages USD 130 for those in coastal forest areas, less than the rest of the country (Rawlani and Sovacool 2011, p. 857), so an additional household income, whether it is USD 600 or USD 1000, would have a major marked impact.

These mangrove afforestation projects were implemented using a cash-for-work system. By the end of 2013, the mangrove plantings used 178,500 man-days of work (UNDP-Bangladesh 2014, p. 18). The project also included planting of other non-mangrove species for improved livelihoods, bringing the total cash-for-work man-days to 464,790 over the duration of the project through the end of 2013 (UNDP-Bangladesh 2014, p. 18). Training was provided to households on subjects related to agriculture, aquaculture, and animal husbandry.

The project has several important weaknesses, especially the breadth of the project. Due to its size, it ran into problems with distributing funds in a timely manner and running behind schedule (UNDP-Bangladesh 2015, p. 4). The training programs did not reach the number of individuals and households that were outlined by the project objectives and goals (UNDP-Bangladesh 2014, p. 7-8). A downside for the mangroves was a lack of a maintenance budget. Young mangrove stands need maintenance to improve seedling survival, and this funding was not available. While the project provided funding for initial plantings, it did not have enough money for a maintenance budget (UNDP-Bangladesh 2015, p. 34). In interviews with local community members and agency stakeholders, the main concern was the replacement of dead seedlings (UNDP-Bangladesh 2015, p. 34-35).

6.1 Clearly Defined Boundaries

This project included a multitude of stakeholders, including federal and international agencies and individual community members. There were more than 16 agencies (UNDP-

Bangladesh 2008, p. 14-16), and 800,000 people impacted by the project site improvements, with tens of thousands of active beneficiaries (UNDP-Bangladesh 2014, p. 7, 18). The project does not describe any ethnic differences, but it mentions a gender difference. Women are often the ones who work on rebuilding after a disaster (Rawlani and Sovacool 2011, p. 852), so the project tried to get women involved, with 43 percent of active beneficiaries being women (UNDPP-ALM 2011). The districts involved in the project are located across central and eastern Bangladesh. The boundaries of the resources and user groups are not well defined and are large in breadth, geographically as well.

6.2 Rules Congruent with Ecological Conditions

Overall, the mangrove afforestation projects, from all five techniques, have contributed to stabilization and growth of mangrove forests, and have allowed for multiple use of land behind coastal forests (UNDP-Bangladesh 2015, p. 33). By 2013, the project had planted over 8,500 hectares of mangrove forests, though it did not state how many of these hectares have survived, as initial plantings are often susceptible to mortality. The project team noticed that its monoculture plantations of *Sonneratia apetala* had a 25 percent survival rate and were not regenerating on their own. The team decided to change planting strategies and plant a ten species mix, including *Heritiera fomes*, *Excoecaria agallocha*, *Xylocarpus mekongensis*, *Cynometra ramiflora*, *Aegiceras corniculatum*, *Bruguiera sexangula*, *Phoenix paludosa*, *Nypa fruticans*, *Lumnitzera racemosa* and *Ceriops dacandra*. It is not clear from the available project documentation the differences in survival and regeneration rates between the monoculture stands and the mixed mangrove stands, or how many of the 8,500 hectares of planted mangrove forests were monoculture and how many were mixed species. In addition, they introduced a salt tolerant rice variety, improving paddy production three-fold in a pilot project (UNDP-Bangladesh 2014,

p. 19). They also planted vegetable and fruit varieties that do well in these climates. These rules help to increase the number of resources, but are not necessarily for managing them sustainably.

6.3 Accountability Mechanism for Monitors

The project had to report the survival rates of plantings, but other than reporting numbers of people who participated in training sessions, cash-for-work, and so on, there is no accountability mechanism. There is also no measure to show that the communities have increased adaptation to climate change, sustainable harvesting of aquaculture resources, or resilient management of mangroves.

6.4 Graduated Sanctions for Violations

There is no mention of violations or sanctions for violations. If a resource is supposed to be managed sustainably, like mangroves, sanctions should be in place for those who harm mangrove forests and newly planted mangroves. The mangroves are the main component for the coastal zone development goal, so having sanctions in place to protect them would be necessary.

6.5 Low-Cost Mechanism for Conflict Resolution

One source of conflict was with the competing interests of the livestock training and mixed agricultural-forest projects, as cattle continued to get into mangrove stands and cropland (UNDP-Bangladesh 2015, p. 22). However, there are no strategies mentioned for dealing with this conflict.

6.6 Informed Discussion of Rules by Interested Parties (Analytic Deliberation)

Those who benefit from this project are not talked about, except in terms of the number of people who participated in different program areas, and in a survey evaluating the end of the project. The resource users are not involved in determining management strategies, only in using the programs that are implemented. The project is very proscribed by the international donors,

having set outcomes and goals without including the thoughts of local community members and politicians until the evaluation stage.

6.7 Allocate Authority for Adaptive Governance (Nesting)

The initial project document set out authority for different components of the project. Authority is given to the Ministry of Forests and the Environment of Bangladesh, in partnership with GEF and UNDP (UNDP-Bangladesh 2008, p. 39). Community organizers have authority over the project in local contexts, and report up the chain of command to the funding partners (UNDP-Bangladesh 2008, p. 77). However, there is no discussion of authority except around the management of funding.

6.8 Mixture of Institutional Types (Institutional Variety)

There is a mix of cash for work, livelihood development, and land lease programs to help increase income for individuals. This does not carry over to management of the mangrove forests and other aquaculture resources.

6.9 SES Diagnostic Framework

This project incorporates two of the eight principles, based on the project materials. Yet the principles that are included are just around funding and the project itself, not on managing the resources of the SES. This may make the governance system less adaptable and could make the SES more susceptible to the realities of climate change. Using the evidence from the project materials, the SES diagnostic framework for this project is described in Figure 6.9.1 and Table 6.9.2. Because this project does not fit many of the initial checklist, it may not be sustainable or resilient in the long run, despite increasing stabilization and growth of the mangrove forests in the short term over the duration of the project. This project is nebulous due to its size, so it has fewer easily definable second-tier variables. It also was not immediately clear how successful the

project has been at protecting existing mangrove stands and aquatic resources, making this SES diagnostic framework incomplete. While the variables in Table 6.3 are mentioned in the “Community-based Adaptation to Climate Change through Coastal Afforestation” project materials, not all of them are currently measured.

Figure 6.9.1. SES Diagnostic Framework for the “Community-based Adaptation to Climate Change through Coastal Afforestation” project in Bangladesh

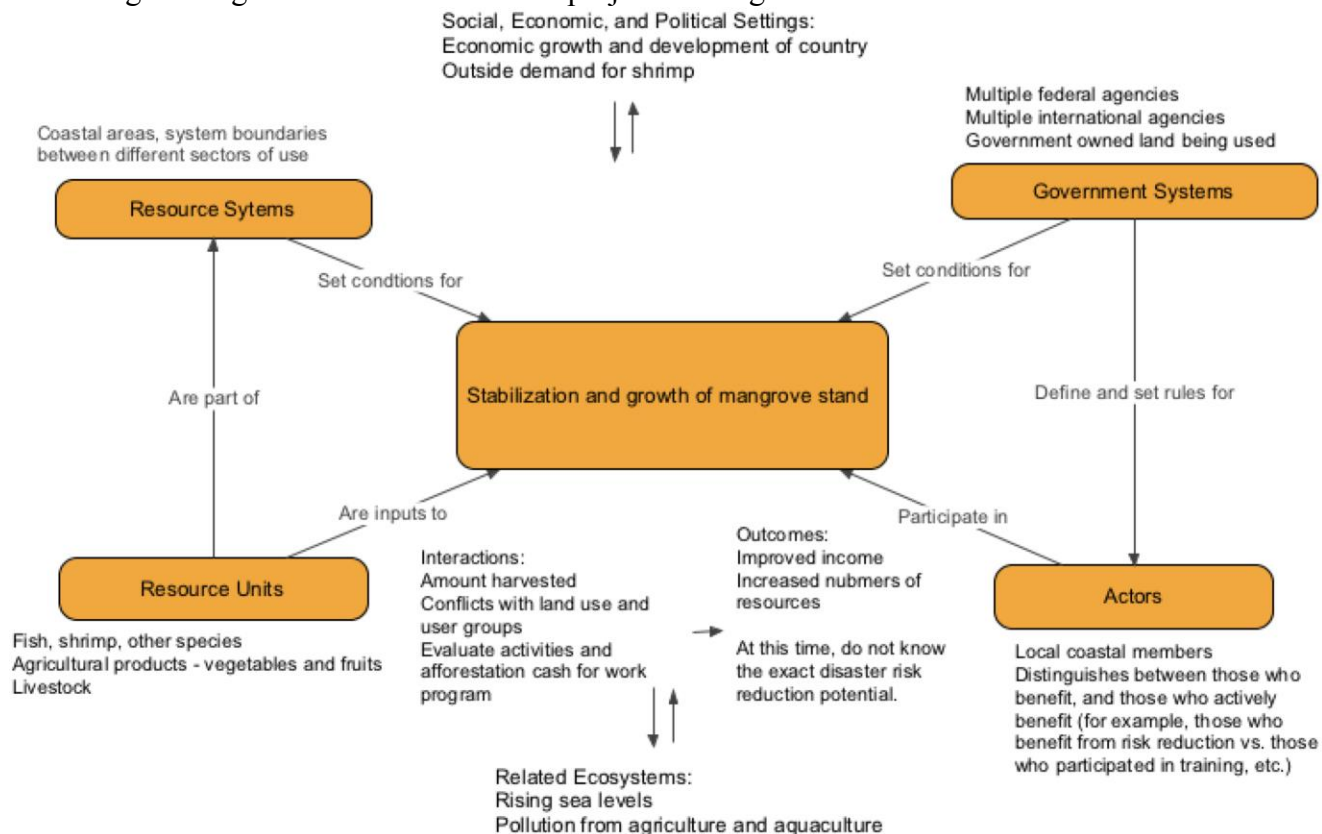


Table 6.9.2. Second-tier diagnostic variables for the “Community-based Adaptation to Climate Change through Coastal Afforestation” project in Bangladesh

Diagnostic framework components	Indicators	Description
S1: Economic Development	Improved Income Livelihood changes	Improved income, especially for those who use 3F model
S5: Markets	Outside demand for shrimp Outside demand for other aquaculture products	Impacts how the land might end up being used
ECO3: Flows in and out of focal SES	Outside users	Freeloaders situations are possible, but not mentioned in project materials

RS1: Sector	Aquaculture Agriculture	Area of sectors, compared to area of mangrove forests
RS2: Clarity of system boundaries	Set boundaries	No clearly set boundaries for the projects, though there were a few pilot studies
RS3: Size of the resource system	Area of each land use sector	Related to RS1
RS5: Productivity of system	Production of marketable materials	Growth of sectors with marketable materials
RS9: Location	Geographic Location	The location of the different projects, and of the different systems within the coastal area
GS1: Government organizations	Who they are and how they related to the management	Multiple, too many to count
GS4: Property Rights	Property, especially used for 3F model, owned by government	Government owned land, set the use standards
RU4: Economic value	Value of the unit	Price of the resource
RU5: Number of units	Number of the units	Whether the resource is decreasing or increasing in number, especially of new agricultural products
A1: Number of actors	Number of people in system	Poorly defined, especially as the number of people impacted by project is high
A2: Socioeconomic attributes	Annual household income	Differences in income, with poorer nearer to the coast
A8: Importance of resource (dependence)	Livelihood reliance ratio	How many actors rely on this coastal zone for livelihood
I1: Harvesting	Amount collected	Can reflect how sustainable the collection is over time
I2: Information sharing	Outcomes from management strategies	Done by the UNDP-ALM branch
I4: Conflicts	Differences in wanted use between groups	Cattle mentioned by local community members in evaluation report
I9: Monitoring activities	What has happened with the resource	Monitoring structured by UNDP; current strategy unclear
I10: Evaluate activities	What activity works best	Which strategies are having the best impact; has focused on afforestation techniques
O2: Ecological Performance	How resource is improving, specifically mangroves	Mangroves tied to benefits in many aquatic sectors, so improvements here will most likely mean improvements for ecological system of the site

Source: Adapted based on MacNeil and Cinner 2013, p. 1395, Table 1

7. Case Comparison

The coastal areas of Bangladesh and Vietnam face several concerning climate change problems, including increases in floods from more intense storms and storm surges. Both have similar coastal livelihood patterns, relying on rice production, other agricultural products, fisheries, and aquaculture (Schmitt 2009, p.4; Rawlani and Sovacool 2011, p. 853). The “Management of Natural Resources in the Coastal Zone of Soc Trang Province” project in Vietnam and the “Community-based Adaptation to Climate Change through Coastal Afforestation” project in Bangladesh focus on improving climate resiliency in delta areas specifically, through mangrove management and afforestation. However, neither project mentioned the extent to which their projects will provide disaster risk reduction, though both touch on vulnerability and resiliency. On a general level, the Vietnam case followed more of the principles for robust governance of environmental resources than the Bangladesh case (based on Dietz, et al. 2003). A comparison of the two projects across these eight principles for governing the commons can be seen in Table 7.1. This could make the Vietnam case more adaptable and resilient in the face of climate change. This becomes clearer in the SES diagnostic framework.

Table 7.1. Case comparison across the eight design principles

Principle	Vietnam Project	Bangladesh Project
Clearly define the boundaries of resources and user groups	x	x (limited)
Devise rules that are congruent with ecological conditions	x	---
Devise accountability mechanisms for monitors	---	---
Apply graduated sanctions for violations	x	---
Establish/use low-cost mechanisms for conflict resolution	x	---
Involve interested parties in informed discussion of rules (analytic deliberation);	x	---
Allocate authority to allow for adaptive governance at multiple levels from local to global (nesting)	x	x (limited)
Employ mixtures of institutional types (institutional variety)	x	---

Although the projects have similar goals and objectives, there are major differences in the projects and their success, as can be seen through the eight principles and the SES diagnostic framework. In the Bangladesh project, many more government systems were included at both the federal and international level compared to the project in Vietnam. This could be part of the reason for the delay in receipt of funds, as oversight was spread thinly over a larger area and across programs beyond afforestation. The area under management is less defined in the Bangladesh project, creating an incomplete SES; without well-defined boundaries, it is challenging to see the interactions between the systems. Seeing the interactions can help to evaluate the project and to see what variables might need tweaking to create the sought outcomes. This can be seen in the case in Vietnam: second-tier variables are more easily identified because the land area under management is more precisely stipulated. This allows the evaluator to see how the actors, government systems, resource systems, and resource units interact with each other to create the desired outcome of a sustainable mangrove forest.

The Vietnam project also had stronger Actors than the Bangladesh one. In Bangladesh, Actors only provided input at set intervals, mostly at the end of the project to provide feedback on improvements. In Vietnam, the Actors were included in defining what was to be harvested, how, and what the monitoring strategies would be. UNDP and other project partners for the Bangladesh case did the monitoring and evaluation. By allowing the Actors to participate in these functions, the Vietnamese project brought society closer to the environment, allowing Actors to see and understand more of their impact on the ecological systems that they are a part of. The co-management strategy tested in Au Tho B appears to have provided significant improvements to the stability of the mangrove ecosystem, and therefore to the livelihoods of the Actors as they rely highly on aquaculture resources.

The Bangladesh project had more diverse Resource Units than the Vietnamese project. Part of this is due to the extensive goals of the project, which went beyond sustainable use of coastal systems to improved resilience of communities. As such, this project included more than just mangrove afforestation, looking to turn fallow land behind mangrove forests into mixed-use agriculture and aquaculture to create resilient livelihoods. This was done using the 3F model, planting vegetables, fruit trees, and providing space for fish aquaculture ponds fed by rainfall. It also provided land to those who were previously landless. This project focused on disaster risk reduction from a social vulnerability angle, instead of an ecological systems perspective (UNDP-Bangladesh 2008, 6).

Both projects skirt around the fact that there are larger social issues at play that have an instrumental role in the social vulnerability of particular individuals. These projects do not discuss why certain people live where they do and why some groups are more affected by coastal climate change impacts than others. There must be deep historical reasons why the Khmer people live between the dikes and mangrove forests in Vietnam and why the coastal people of Bangladesh are much poorer and landless than other Bangladeshis. The social issues are particularly noticeable in the project materials from the Bangladesh case. It was a journal article discussing the project that first mentioned the large income disparities between coastal households and others in Bangladesh. These social differences are not apparent in the project material itself. The reports are so political sterile, there is not enough information to elaborate on the SES of Bangladesh or to fully evaluate how it fits with the eight principles checklist.

The cases did provide further information on planting mangroves that may be helpful. For example, the project in Bangladesh found that monoculture forests of *Sonneratia apetala* do not regenerate well on their own, and therefore having mixed species helps with survival rates and

regeneration later on. This project used a mix of ten species in replanting efforts after realizing that the monoculture plantations were not surviving well. The Vietnam project found that less dense plantings survive better than plantings where the mangroves are too close together, with 5 and 9 seedlings per square meter having higher survival rates than planting densities of 21 and 35 seedlings per square meter. This information is important for other mangrove management projects to consider before implementation.

8. Recommendations and Conclusion

This paper makes six recommendations to international agencies and NGOs looking to implement mangrove projects for disaster risk reduction purposes. Mangroves can be considered green infrastructure and tools in disaster risk reduction, which could help to reduce the impacts of flooding events while improving livelihoods. However, this report has shown there can be many factors that can result in a gap between intent and the outcomes. The risk framework and definition used in DRR projects by international agencies is missing social vulnerability and resilience components. The *first recommendation* is to modify the existing framework to incorporate social vulnerability and resiliency, like in Figure 2.2.1.1, bringing a human element to risk reduction. Mangroves reduce social vulnerability by improving the quantity of aquaculture resources. The disaster risk reduction potential of mangroves is hard to quantify, especially as mangrove ecosystems also tie into the livelihood and vulnerability of coastal populations. It is clear from these cases that green infrastructure – or at least mangroves – may provide both risk reduction and other benefits, if paired with livelihood programs.

Yet these cases do not provide an answer as to whether or not mangrove projects outweigh other projects that reduce social vulnerability, such as improved access to education and relocating people to areas that are at lower risk to climate change impacts. Mangroves may

not be the be-all and end-all of DRR projects for coastal areas. This just happened to be the focus of this paper. The *second recommendation* is for further study on the disaster risk reduction potential of mangroves to better compare it to other projects that reduce social vulnerability, especially if the main implementation of mangroves is for DRR purposes. These studies should explore the outcomes of mangroves, including the: 1) survival rate of different plantings; 2) regeneration potential; 3) maintenance vs. initial planting; 4) develop measures for livelihood improvement; and 5) develop social vulnerability indices. If mangroves are not the most beneficial project for reducing disaster risk and social vulnerability, these agencies should consider other kinds of projects.

Another factor to keep in mind with using mangroves for green infrastructure is the fact that the stands may break when first impacted by an intense wave. If a storm or tsunami were to hit either of these project areas in the next few areas, these newly planted mangroves would most likely not survive. If a second storm or tsunami were to hit soon after, the mangroves would probably not be there to reduce exposure risk, as they take time to regenerate. The *third recommendation* is for an NGO or international agency to consider implementing a dike and mangroves system instead of mangroves alone. The mangroves would be planted on the ocean side of the dike, working to dissipate wave energy before it reaches the dike. This helps reduce the cost of dike repairs as well. This can provide similar ecosystem benefits but provide an extra layer of risk reduction for those who live on the land side of the dike.

The Social-Ecological System diagnostic framework, developed by Elinor Ostrom, shows the interactions between mangroves and social systems, and informs how these interactions can be better managed to improve mangrove stands. It shows how the users and actors interact, what variables may need to be tweaked, and can also be used as method of comparison. The *fourth*

recommendation is to use this framework as a tool for evaluating the implementation of disaster risk reduction and green infrastructure projects. One of the limitations of the Bangladesh project is that it does not have well defined boundaries. For a social-ecological system to work well, the boundaries need to be defined between user groups and resources. However, when a project has well defined boundaries and is smaller in size, such as the case from Vietnam, the interactions between variables are easier to identify. It also can be used as a method of comparison to see how two projects with similar goals and outcomes differ. While the Vietnam and Bangladesh cases had similar goals and outcomes in the short-term, the project in Vietnam had stronger Actor variables, while the project in Bangladesh had stronger Resource Unit variables. Yet both projects worked to stabilize and grow the local mangrove stands, at least in the short run.

As NGOs and international agencies look to develop mangrove management and afforestation projects, these cases provide a few important considerations. The *fifth recommendation* is to use the eight principles for governing the commons to inform best practices for project design. Based on these design principles, the Vietnam case appears to be better suited for the long term, mostly due to its implementation of co-management. The Bangladesh case presents an alternative mangrove restoration strategy that uses coastal government land to supply the landless with the ability to grow food and fish, while also providing space for mangrove trees. This provides risk reduction on multiple fronts, both in exposure and in vulnerability, as mangroves help to break flood waves and locals are given an opportunity to expand and diversify their livelihood opportunities. The *sixth recommendation* is to continue learning from case studies, such as the ones in this report, to yield improved approaches for implementing green infrastructure for disaster risk reduction.

A mangrove management project is only as successful as its ability to continue growing after an NGO or international agency has left. Mangrove rehabilitation and planting efforts are of little use if the stands are not protected afterward (Schmitt, et al. 2013, p. 547). If causes of mangrove destruction and degradation are not reversed, then the projects will also have a hard time meeting their intended objectives and will not last very long (Adger, et al. 2005, p. 1038). In Vietnam, the Actors were highly involved in the governing and monitoring structures that were created to manage the local mangrove stand. By allowing for co-management during project implementation, community members can understand the importance of these ecosystems and be able to continue the project even after it has officially ended. The SES diagnostic framework provides a way to look at projects beyond the ecological benefits to understand the social drivers of environmental change. If mangrove projects incorporate social considerations and evaluate the interactions between the social and environmental systems, the mangrove stands – and their benefits – will hopefully last for many decades to come.

Bibliography

- Adger, W. Neil. 1999. "Social vulnerability to climate change and extremes in coastal Vietnam." *World Development* 27 (2): 249-269.
- Adger, W. Neil, Terry P Hughes, Carl Folke, Stephen R Carpenter, and Johan Rockström. 2005. "Social-Ecological Resilience to Coastal Disasters." *Science* 309 (5737): 1036–39. doi:10.1126/science.1112122.
- Agrawal, Arun. 2001. "Common property institutions and sustainable governance of resources." *World Development* 29 (10): 1649-1672.
- Ban, Natalie C., Morena Mills, Jordan Tam, Christina C. Hicks, Sarah Klain, Natalie Stoeckl, Madeleine C. Bottrill, Jordan Levine, Robert L. Pressey, Terre Satterfield, and Kai M.A. Chan. 2013. "A social-ecological approach to conservation planning: embedding social considerations." *Frontiers in Ecology and the Environment* 11 (4): 194-202.
- Bosire, Jared O., Farid Dahdouh-Guebas, M. Walton, B. I. Crona, R. R. Lewis, Colin Field, James G. Kairo, and Nico Koedam. 2008. "Functionality of restored mangroves: a review." *Aquatic Botany* 89 (2): 251-259.
- CBACC-CF Project. 2014. "About Project." United Nations Development Programme. http://www.cbacc-coastalaffor.org.bd/index.php?option=com_content&view=article&id=1318&Itemid=29
- ci:grasp. n.d. "Management of natural resources in the coastal zone (Soc Trang province, Viet Nam)." *The Climate Impacts: Global and Regional Adaptation Support Platform, Potsdam Institute for Climate Impact Research*. http://www.pik-potsdam.de/~wrobel/ci_2/adaptation_projects/485.html
- Cinner, Joshua E., M. Aaron MacNeil, Xavier Basurto, and Stefan Gelcich. 2013. "Looking beyond the fisheries crisis: Cumulative learning from small-scale fisheries through diagnostic approaches." *Global Environmental Change* 23 (6): 1359-1365.
- Cochard, R. 2011. "The 2004 Tsunami in Aceh and Southern Thailand: Coastal Ecosystem Services, Damages and Resilience." In N.A. Mörner (ed.), *The Tsunami Threat – Research and Technology*. Vienna: InTech, 179–216.
- Cooley, H., E. Moore, M. Heberger, and L. Allen (Pacific Institute). 2012. *Social Vulnerability to Climate Change in California*. California Energy Commission. Publication Number: CEC-500-2012-013.
- Costanza, Robert, and Joshua Farley. 2007. "Ecological economics of coastal disasters: Introduction to the special issue." *Ecological Economics* 63 (2): 249-253.

- Cutter, Susan L., Bryan J. Boruff, and W. Lynn Shirley. 2003. "Social vulnerability to environmental hazards." *Social science quarterly* 84 (2): 242-261.
- Cutter, Susan L., Lindsey Barnes, Melissa Berry, Christopher Burton, Elijah Evans, Eric Tate, and Jennifer Webb. 2008. "A place-based model for understanding community resilience to natural disasters." *Global Environmental Change* 18 (4): 598-606.
- Dahdouh-Guebas, Farid, Loku Pulukkuttige Jayatissa, Diana Di Nitto, Jared O. Bosire, D. Lo Seen, and Nico Koedam. 2005. "How effective were mangroves as a defense against the recent tsunami?" *Current Biology* 15 (12): 443-447.
- Das, Saudamini, and Jeffrey R. Vincent. 2009. "Mangroves protected villages and reduced death toll during Indian super cyclone." *Proceedings of the National Academy of Sciences* 106 (18): 7357-7360.
- Davies, C., R. MacFarlane, C. McGloin, and M. Roe. 2008. *Green Infrastructure Planning Guide*. North East Community Forests, UK.
http://www.aughty.org/pdf/green_infrastruct_planguide.pdf
- Dietz, Thomas, Elinor Ostrom, and Paul C. Stern. 2003. "The struggle to govern the commons." *Science* 302 (5652): 1907-1912.
- Dow Chemical Company, Shell, Swiss Re, Unilever, and The Nature Conservancy. 2013. "The Case for Green Infrastructure" and "Green Infrastructure Case Studies." Joint-Industry White Papers. <http://www.nature.org/about-us/the-case-for-green-infrastructure.pdf>,
<http://www.nature.org/about-us/working-with-companies/case-studies-for-green-infrastructure.pdf>
- Dunn, Alexandra Dapolito. 2010. "Sitting Green Infrastructure: Legal and Policy Solutions to Alleviate Urban Poverty and Promote Healthy Communities." *Boston College Environmental Affairs Law Review* 41: 41-66.
<http://digitalcommons.pace.edu/cgi/viewcontent.cgi?article=1557&context=lawfaculty>.
- Earth Observatory. 2010. "Mapping Mangroves by Satellite." NASA, November 30.
<http://earthobservatory.nasa.gov/IOTD/view.php?id=47427>
- Ellison, Aaron M. 2000. "Mangrove restoration: do we know enough?" *Restoration Ecology* 8 (3): 219-229.
- Feagin, Rusty A., Nibedita Mukherjee, Kartik Shanker, Andrew H. Baird, Joshua Cinner, Alexander M. Kerr, Nico Koedam, Aarthi Sridhar, Rohan Arthur, L.P. Jayatissa, Danny Lo Seen, Manju Menon, Sudarshan Rodriguez, Md. Shamsuddoha, and Farid Dahdouh-Guebas. 2010. "Shelter from the storm? Use and misuse of coastal vegetation bioshields for managing natural disasters." *Conservation Letters* 3 (1): 1-11.
- Füssel, Hans-Martin, and Richard J.T. Klein. 2006. "Climate change vulnerability assessments: an evolution of conceptual thinking." *Climatic Change* 75 (3): 301-329.

- Gill, S. E., J. F. Handley, A. R. Ennos, and Stephan Pauleit. 2007. "Adapting cities for climate change: the role of the green infrastructure." *Built Environment* 33 (1): 115-133.
- Giri, C., Z. Zhu, L. L. Tieszen, A. Singh, S. Gillette, and J. A. Kelmelis. 2008. "Mangrove forest distributions and dynamics (1975–2005) of the tsunami-affected region of Asia." *Journal of Biogeography* 35 (3): 519-528.
- GIZ. 2013. "Mangrove Management." *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)*, November. http://daln.gov.vn/r/files/ICMP-CCCEP/tai_lieu/Factsheets/Soc-Trang/EN-Fact-Sheet-Mangrove-Management-2013.pdf
- Glaser, Marion, and Bernhard Glaeser. 2014. "Towards a framework for cross-scale and multi-level analysis of coastal and marine social-ecological systems dynamics." *Regional Environmental Change* 14 (6): 2039-2052.
- Gleditsch, Nils Petter. 2012. "Whither the weather? Climate change and conflict." *Journal of Peace Research* 49 (1): 3-9.
- Greenway, Twilight. 2012. "Is your all-you-can-eat shrimp killing the mangroves?" *Grist.com*, January 4. <http://grist.org/food/2012-01-03-is-your-all-you-can-eat-shrimp-killing-the-mangroves/>.
- Ha, Tran Thi Thu, Simon R. Bush, Arthur PJ Mol, and Han van Dijk. 2012. "Organic coasts? Regulatory challenges of certifying integrated shrimp–mangrove production systems in Vietnam." *Journal of Rural Studies* 28 (4): 631-639.
- Iftekhar, M. S., and T. Takama. 2008. "Perceptions of biodiversity, environmental services, and conservation of planted mangroves: a case study on Nijhum Dwip Island, Bangladesh." *Wetlands Ecology and Management* 16 (2): 119-137.
- IUCN. 2010. "Co-management and governance in Vietnam: some reflections." *International Union for Conservation of Nature*, April 7. <http://www.iucn.org/about/work/programmes/forest/?5020/1/Co-Management-and-Governance-in-Vietnam-Some-Reflections>
- Jones, Holly P., David G. Hole, and Erika S. Zavaleta. 2012. "Harnessing nature to help people adapt to climate change." *Nature Climate Change* 2 (7): 504-509.
- Kathiresan, Kandasamy and Narayanasamy Rajendran. 2005. "Coastal mangrove forests mitigated tsunami." *Estuarine, Coastal and Shelf Science* 65 (3): 601-606.
- Kazmierczak, Aleksandra, and Jeremy Carter. 2010. *Adaptation to climate change using green and blue infrastructure: A database of case studies*. University of Manchester: GRaBS project. http://www.grabs-eu.org/membersArea/files/Database_Final_no_hyperlinks.pdf

- Kellett, Jan, and Alice Caravani. 2013. *Financing Disaster Risk Reduction*. London: Overseas Development Institute and Global Facility for Disaster Reduction and Recovery (World Bank). http://www.drrinacp.org/sites/drrinacp.org/files/publication/Financing-DRR_Publication_0.pdf
- Kerr, Alexander M., Andrew H. Baird, and Stuart J. Campbell. 2006. "Comments on 'Coastal mangrove forests mitigated tsunami' by K. Kathiresan and N. Rajendran." *Estuarine, Coastal and Shelf Science* 67 (3): 539-541.
- Lemos, Maria Carmen, and Arun Agrawal. 2006. "Environmental governance." *Annual Review of Environment and Resources* 31: 297-325.
- Li, Xiaokai, Marcel Marchand, and Weihua Li. 2012. *Grow in Concert with Nature: Green water defense for flood risk management in East Asia*. An EASSD discussion paper. Washington DC : World Bank. http://www-wds.worldbank.org/external/default/WDSPContentServer/WDSP/IB/2013/01/24/000356161_20130124130230/Rendered/PDF/NonAsciiFileName0.pdf
- Lloyd, Richard. 2010. *Management of Natural Resources in the Coastal Zone of Soc Trang Province: Co-Management in Au Tho B Village – A pilot test for the coastal zone of Soc Trang Province*. Soc Trang City, Vietnam: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. http://daln.gov.vn/r/files/ICMP-CCCEP/tai_lieu/Document/Soc-trang/2010/Co-Management-Au-Tho-B-2010-EN.pdf
- MacNeil, M. Aaron, and Joshua E. Cinner. 2013. "Hierarchical livelihood outcomes among co-managed fisheries." *Global Environmental Change* 23 (6): 1393-1401.
- McGinnis, M. D., and E. Ostrom. 2014. "Social-ecological system framework: initial changes and continuing challenges." *Ecology and Society* 19 (2): 30-41.
- McMahon, Edward T, and M.A. Benedict. 2006. "Green Infrastructure: Smart Conservation for the 21st Century." *Sprawl Watch Clearing House Monograph Series*. Washington, D.C.: Sprawl Watch Clearing House. <http://www.sactree.org/assets/files/greenprint/toolkit/b/greenInfrastructure.pdf>.
- Marchand, M., TrinhThi Long, and Sawarendro. 2012. *Adaptive Water Management for Delta Regions: Towards Green Defense in East Asia*. Report written by Deltares for the World Bank. dtvirt35.deltares.nl/products/30103
- Naumann, Sandra, McKenna Davis, Timo Kaphengst, Mav Pieterse, and Matt Rayment. 2010. *Design, implementation and cost elements of Green Infrastructure projects*. Brussels: European Commission, DG Environment. Ecologic institute and GHK Consulting. http://ec.europa.eu/environment/enveco/biodiversity/pdf/GI_DICE_FinalReport.pdf

- O'Brien, Karen, Siri Eriksen, Lynn P. Nygaard, and Ane Schjolden. 2007. "Why different interpretations of vulnerability matter in climate change discourses." *Climate Policy* 7 (1): 73-88.
- Ostrom, Elinor. 2007. "A diagnostic approach for going beyond panaceas." *Proceedings of the National Academy of Sciences* 104 (39): 15181-15187.
- Ostrom, Elinor. 2009. "A general framework for analyzing sustainability of Social-Ecological Systems." *Science* 325 (5939): 419-422.
- PanNature. 2010. *Management of Natural Resources in the Coastal Zone of Soc Trang Province: Awareness Survey and Assessment on the Environmental and Coastal Natural Resource Management of Soc Trang Province*. Soc Trang City, Vietnam: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH. http://www.nature.org.vn/en/wp-content/uploads/2015/01/08012015_PanNature-Awareness-Assessment-2010-EN.pdf
- Rawlani, Amireeta K., and Benjamin K. Sovacool. 2011. "Building responsiveness to climate change through community based adaptation in Bangladesh." *Mitigation and Adaptation Strategies for Global Change* 16 (8): 845-863.
- Renaud, Fabrice G, Karen Sudmeier-Rieux, and Marisol Estrella, eds. 2013. *The Role of Ecosystems in Disaster Risk Reduction*. New York: United Nations University Press. <http://i.unu.edu/media/unu.edu/publication/34178/1221-Role-of-Ecosystems-SAMPLE-CHAPTER.pdf>.
- Sayers, Paul, Li Yuanyuan, Gerry Galloway, Edmund Penning-Rowsell, Shen Fuxin, Wen Kang, Chen Yiwei, and Tom LeQuesne. 2013. *Flood Risk Management: A Strategic Approach*. Paris: UNESCO. <http://www.sayersandpartners.co.uk/uploads/6/2/0/9/6209349/flood-risk-management-web.pdf>.
- Schmitt, Klaus. 2009. *Management of Natural Resources in the Coastal Zone of Soc Trang Province: Protection and sustainable use of coastal wetlands through co-management and mangrove rehabilitation with emphasis on resilience to climate change*. Soc Trang City, Vietnam: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. http://daln.gov.vn/r/files/ICMP-CCCEP/tai_lieu/Document/Soc-trang/2009/Mangrove-protection-and-co-management-Soc-Trang-2009.pdf
- Schmitt, Klaus, T. Albers, T. T. Pham, and S. C. Dinh. 2013. "Site-specific and integrated adaptation to climate change in the coastal mangrove zone of Soc Trang Province, Viet Nam." *Journal of Coastal Conservation* 17 (3): 545-558.
- Slovic, Paul, and Elke U. Weber. 2002. "Perception of Risk Posed by Extreme Events." Working paper. New York: Center for Decision Sciences (CDS), Columbia University. <http://www.rff.org/Documents/Events/Workshops%20and%20Conferences/Climate%20Change%20and%20Extreme%20Events/slovic%20extreme%20events%20final%20geneva.pdf>

- Spalding, Mark D., Anna L. McIvor, Michael W. Beck, Evamaria W. Koch, Iris Möller, Denise J. Reed, Pamela Rubinoff, Thomas Spencer, Trever J. Tolhurst, Ty V. Wamsley, Bregje K. van Wesenbeeck, Eric Wolanski, and Colin D. Woodroffe. 2014. "Coastal ecosystems: a critical element of risk reduction." *Conservation Letters* 7 (3): 293-301.
- Stewart, Jeanine. 2015. "Vietnam supplier doubling production of organic black tigers this year." *Undercurrentnews.com*, March 13. <http://www.undercurrentnews.com/2015/03/13/vietnam-supplier-doubling-production-of-organic-black-tigers-this-year/>
- Sultana, Rumana, S. Rafiqul Alam Rumi, and MA Hanif Sheikh. 2013. "Climate Change Induced Flood Risk and Adaptation in the Padma River Island, Bangladesh: A Local Scale Approach." *Journal of Life and Earth Science* 8: 41-48.
- Tanaka, Norio. 2009. "Vegetation bioshields for tsunami mitigation: review of effectiveness, limitations, construction, and sustainable management." *Landscape and Ecological Engineering* 5 (1): 71-79.
- The Nature Conservancy. 2015. *The Potential of Nature Based Approaches in Flood Risk Management*. Draft Report (unpublished).
- Thu, Phan Minh, and Jacques Populus. 2007. "Status and changes of mangrove forest in Mekong Delta: Case study in Tra Vinh, Vietnam." *Estuarine, Coastal and Shelf Science* 71 (1): 98-109.
- Tompkins, Emma L., Adelina Mensah, Lesley King, Tran Kim Long, Elaine T. Lawson, Craig W. Hutton, Viet Anh Hoang, Chris Gordon, Marianne Fish, Jen Dyer, and Nadia Bood. 2013. "An investigation of the evidence of benefits from climate compatible development." Leeds, UK: Sustainable Research Institute, Centre for Climate Change Economics and Policy, University of Leeds. <http://eprints.soton.ac.uk/349080/1/SRIPs-44-Tompinsetal-triplewins-Jan2013.pdf>
- Troeh, Eve. 2014. "Reporter's Notebook: Exploring The Mekong Delta." *New Orleans Public Radio*, November 26. <http://wno.org/post/reporters-notebook-exploring-mekong-delta>
- Tuan, Tran Huu, and Bui Duc Tinh. 2013. "Cost-benefit analysis of mangrove restoration in Thi Nai Lagoon, Quy Nhon City, Vietnam." Work Paper, Asian Cities Climate Resilience Working Paper Series. London: International Institute for Environment and Development. <http://pubs.iied.org/pdfs/10644IIED.pdf?>
- Tzoulas, Konstantinos, Kalevi Korpela, Stephen Venn, Vesa Yli-Pelkonen, Aleksandra Kaźmierczak, Jari Niemela, and Philip James. 2007. "Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review." *Landscape and urban planning* 81 (3): 167-178.
- UNDP-ALM. 2011. *Bangladesh Case Study: Community-based Adaptation to Climate Change through Coastal Afforestation in Bangladesh (CBACC-CF Project)*. United Nations

- Development Programme. http://www.undp-alm.org/sites/default/files/downloads/undp-alm_case_study_bangladesh_case_study_-_november_2011_v9.pdf
- UNDP-Bangladesh. 2008. *Community-based Adaptation to Climate Change through Coastal Afforestation in Bangladesh*. 29 July. United Nations Development Programme. <http://cbacc-coastalaffor.org.bd/projectdocument/project3.pdf>
- UNDP-Bangladesh. 2014. *Annual Progress Report 2013: Community-based Adaptation to Climate Change through Coastal Afforestation in Bangladesh*. United Nations Development Programme. <http://cbacc-coastalaffor.org.bd/projectdocument/progress2013.pdf>
- UNDP-Bangladesh. 2015. *Draft Final Report: Community-based Adaptation to Climate Change through Coastal Afforestation in Bangladesh*. United Nations Development Programme. <http://cbacc-coastalaffor.org.bd/projectdocument/CBACCA-CF-M&E-Final%20Draft%20Report.pdf>
- UNISDR. 2012. "What Is Disaster Risk Reduction?" United Nations Office for Disaster Risk Reduction. <http://www.unisdr.org/who-we-are/what-is-drr>.
- U.S. EPA Water. 2014. "What is Green Infrastructure?" *U.S. Environmental Protection Agency*. http://water.epa.gov/infrastructure/greeninfrastructure/gi_what.cfm
- van Bochove, J., E. Sullivan, and T. Nakamura (eds). 2014. *The Importance of Mangroves to People: A Call to Action*. United Nations Environment Programme. Cambridge: World Conservation Monitoring Centre. http://apps.unep.org/publications/index.php?option=com_pmtdata&task=download&file=-The%20importance%20of%20mangroves%20to%20people_%20a%20call%20to%20action-2014Mangrove.pdf
- van Lavieren, Hanneke, Mark Spalding, Daniel M. Alongi, Mami Kainuma, Miguel Clüsener-Godt, and Zafar Adeel. 2012. *Policy Brief: Securing the Future of Mangroves*. Hamilton, Canada: UNU-INWEH, UNESCO-MAB with ISME, ITTO, FAO, UNEP-WCMC and TNC. <http://inweh.unu.edu/wp-content/uploads/2013/05/Securingfuturemangroves.pdf>
- Vermaat, Jan E., and Udomluck Thampanya. 2006. "Mangroves mitigate tsunami damage: A further response." *Estuarine, Coastal and Shelf Science* 69 (1): 1-3.
- Walton, Mark EM, Giselle PB Samonte-Tan, Jurgenne H. Primavera, Gareth Edwards-Jones, and Lewis Le Vay. 2006. "Are mangroves worth replanting? The direct economic benefits of a community-based reforestation project." *Environmental Conservation* 33 (4): 335-343.
- World Bank. 2013. *Building Resilience: Integrating Climate and Disaster Risk into Development*. Washington, D.C.: International Bank for Reconstruction and Development (World Bank). http://www.worldbank.org/content/dam/Worldbank/document/SDN/Full_Report_Building_Resilience_Integrating_Climate_Disaster_Risk_Development.pdf.

Zevenbergen, Chris, Adrian Cashman, Niki Evelpidou, Erik Pasche, Stephen Garvin, and Richard Ashley. 2010. *Urban Flood Management*. Boca Raton, Florida: CRC Press.

Zhang, Keqi, Huiqing Liu, Yuepeng Li, Hongzhou Xu, Jian Shen, Jamie Rhome, and Thomas J. Smith. 2012. "The role of mangroves in attenuating storm surges." *Estuarine, Coastal and Shelf Science* 10: 11-23.